D.3 Main Routes

The routes selected for potential marine transport are discussed in Appendix C. These routes cover the transport of the spent nuclear fuel from the country of origin to the first port of call in the United States. In the port incident-free and accident analysis it has been assumed that the vessel carrying the spent nuclear fuel would not unload the material at its first port of call. Intermediate port calls have been assumed in the analysis. In the marine impact accident and incident-free analysis, the intermediate port calls result in additional travel time which has been incorporated into both analyses. In the port analysis, this results in additional workers who could be affected by incident-free impacts and additional locations where accidents could occur. Due to the large variability associated with the movement of the vessel between U.S. ports, no specific route has been identified for use in the analysis. With the approach used in this analysis, the specific routes used between the U.S. ports would not affect the results of the risk assessment.

D.4 Accident-Free Impacts: Methods and Results

D.4.1 Introduction

This section of the appendix provides an overview of the approach used to assess the risks associated with port activities involved in transferring the spent nuclear fuel from the vessel to a vehicle for transport to the management site. Included here is a discussion of the incident-free risk assessment methodology and the results of the analyses, including an assessment of the cumulative risk associated with the marine transportation of the foreign research reactor spent nuclear fuel through U.S. ports.

The risk assessment results are presented in terms of a per shipment risk, annual risks from incident-free transport, as well as for the total risks associated with the program.

D.4.2 Scope

All foreign research reactor spent nuclear fuel shipments that would require ocean transport are expected to occur via one of four types of vessels: container ships, roll-on/roll-off vessels, general cargo (breakbulk) vessels, or purpose built vessels. In the incident-free analysis, it has been assumed that all shipments are made on either a breakbulk or a container vessel, an assumption intended to provide bounding assessments of the risks associated with port activities required for the transfer of spent nuclear fuel.

D.4.2.1 Nonradiological Risk of Marine Transportation Related Activities

This portion of the risk assessment is limited to estimating the human health risks incurred during spent nuclear fuel unloading and handling during port operations at U.S. ports and during the vessel's approach to the port and movement within the port. The nonradiological risks from these activities were assessed as resulting in a negligible impact on the health of the public and workers. Approximately 56,000 port calls involving vessels engaged in foreign trade are made at U.S. ports every year (DOC, 1994). As discussed in Appendix C, each of these vessels has the capacity to carry hundreds of pieces of cargo of the size of a container carrying a spent nuclear fuel transportation cask (typically, container vessels carry between 800-1,000 containers, while some carry many more). This translates to millions of pieces of cargo every year. To fulfill the needs of the basic implementation of Management Alternative 1 of the proposed action, less than 60 transportation casks would need to be shipped per year. This is less than 0.001 percent of the total number of pieces of cargo (originating in foreign countries) to be handled at U.S. ports each year. The limited number of shipments per year should not result in a significant change to the risks to the public including the port workers.

D.4.2.2 Radiological Risks of Marine Transportation

The risks that result from the radioactive nature of the shipments are addressed for both incident-free transportation and accident conditions. The radiological risks associated with the incident-free shipping conditions result from the potential exposure of members of the crew and dock workers to external radiation in the vicinity of the packaged fuel. No other exposure is considered, due to the relative isolation of the material from the general public during all phases of the port activities associated with the transfer of the spent nuclear fuel from the ocean going vessel to the overland transportation mode.

All radiologically-related impacts are calculated in terms of committed dose and associated health effects in the exposed populations. The radiation dose calculated is the total effective dose equivalent, which is the sum of the effective dose equivalent (EDE) from the external radiation exposure and the 50-year committed effective dose equivalent from internal radiation exposure. The EDE is the sum of the tissue and organ weighted dose equivalents for all irradiated tissues and organs. The committed effective dose equivalent considers the initial exposure and the effects of radioactive decay and elimination of the radionuclide through ordinary metabolic processes over the 50-year period. Radiation doses are presented in units of person-rem for collective population and rem for individuals. The impacts are further expressed as health risks, primarily in terms of latent cancer fatalities (LCF). The health risk conversion factors were derived from International Commission of Radiological Protection Publication 60 (ICRP, 1991).

D.4.3 Port Facility Operations

This section describes the principal activities that are performed at a port facility to transfer a radioactive material package ("cask") from an ocean vessel to a surface conveyance, such as a truck trailer or railcar. The purpose of this description is to assist in establishing an estimate of the ionizing radiation dose to personnel that could be associated with the port intermodal transfer. The description of activities, and estimates of durations of specific tasks and personnel requirements is presented later in this section.

The off-load operation would take place at a "facility of particular hazard," as defined in 33 CFR 126.05, that is designated by the Captain of the Port. The Captain of the Port is a U.S. Coast Guard officer that enforces, within his/her respective port, safety, security and marine environmental protection regulations. These include, without limitation, regulations for the protection and security of vessels, harbors, and waterfront facilities; anchorages; security of vessels; waterfront facilities; security zones; safety zones; regulated navigation areas; deepwater ports; water pollution; and ports and waterway safety. The Captain of the Port designates and permits "facilities of particular hazard."

Such a facility is allowed to handle "cargoes of particular hazard" including "highway route controlled quantities of radioactive material," which includes spent nuclear fuel. The Captain of the Port could establish a safety zone or security zone around the vessel, if necessary. These zones would prohibit unauthorized personnel from entering the area. Usually a "facility of particular hazard" will have a secured area onsite for the storage of "cargoes of particular hazard." This facility would be used for the temporary storage of spent nuclear fuel, if necessary. Usually, these cargoes are loaded on a truck or train that departs for its destination soon after being checked by a facility employee and inspected by the proper authorities.

Each "facility of particular hazard" has an operations manual that outlines procedures for handling "cargoes of particular hazard," the personnel used and their qualifications, emergency procedures, and contact numbers. Only the Captain of the Port can approve the required operations manual, and only the Captain of the Port can approve any changes made to the operations manual. The content of the operations manuals can vary by port location and size, and by the type of materials handled. The operations manual of the facility under consideration for off-load operations should be studied prior to receipt of any spent nuclear fuel.

D.4.3.1 Intermodal Transfers

The intermodal transfer of the container (or cask) is largely a mechanical lifting operation with somewhat limited personnel participation. Unloading of vessels is generally performed by members of the International Brotherhood of Longshoremen (East Coast and Gulf Ports), or the International Longshoremen and Warehouseman Union ("Longshoreman") (West Coast ports), sometimes with support from the vessel's crew.

There are various configurations of container (or cask) storage aboard ship that could arise. However, as a preference, containers (or casks) are transported below decks. The following sections describe the principal operations that must occur to achieve both transfer of the container (or cask) from the ship, and to prepare it for departure from the port. It should be noted that as a general rule, departure from the port occurs as soon as is practicable, since the intermodal transfer is merely part of an "in progress" transportation activity, and radioactive materials transport should be expeditious. Infrequently, containers (or casks) may be (temporarily) stored at port facilities for some reason, such as bad weather.

D.4.3.1.1 Container Transfer to Truck Trailer or Railcar

If the port routinely receives containerized freight, it will be equipped with a crane adapted to handle containers. These cranes use a spreader bar equipped with International Standards Organization twistlocks at each of its four corners. The length of the spreader bar is automatically adjustable to accommodate the two International Standards Organization standard container lengths of 6.1 m (20 ft) or 12.2 m (40 ft). Casks are normally shipped in the 6.1-m (20-ft) containers. The twistlocks mate with standard fittings in the corner posts of the container, and are automatically actuated by the crane operator to attach the spreader bar to the container. Typically, no personnel are on the container when the spreader bar is attached. Engagement can be verified by the crane operator or, depending on the container stacking arrangement or port practice, by Longshoremen on the deck. The crane operator is in an enclosed cabin and is usually separated by a considerable distance from the cargo. The procedures described below apply to so-called cellular container ships or combination container/breakbulk ships.

Once engaged, the container is lifted from the hold of the ship, up and over the side to a container trailer, or railcar, on the dock. Engaging the container and moving it to the transporter, takes about 1.5 minutes on average (about 45 containers per hour).

The routine unloading is to install the container on a standard over-the-road container trailer which is pulled by a specially made tractor used at ports. These dock tractors have a single person cab and a hydraulically driven "fifth-wheel" which is used to raise the front end of the container trailer much higher than it would be for regular transport. This allows the Longshoremen to move the container trailer without having to raise and lower the trailer front landing gear at each re-positioning of the trailer. The dock tractor then moves the container to a freight staging area, parks it, connects to an empty container trailer, and re-positions under the container crane. Usually, several dock tractors are used to continuously move containers from "under the hook." Dock tractors are not suitable for over-the-road use.

The receiver (or the agent for the receiver) generally arranges with the Longshoremen to install the cask container directly onto the container trailer, or railcar, which will be used for overland transport, and which has already been inspected. The container trailer will be pulled by the tractor which is to be used for transport.

If the containerized cask is placed on a dock container trailer, sometimes called a "bombcart," then it must be later moved to the trailer which is to be used for transport. This transfer can be made using a large, industrial fork lift, top lift, or a small mobile crane ("forklift") specifically designed to move containers in the port freight staging areas. A bombcart is a special container trailer, used only within the port facility, that does not have twistlocks at its four corners to secure the container being loaded or unloaded.

Spotting the container on its designated trailer (or railcar) and securing it using the trailer mounted International Standards Organization locks, requires two (2), or four (4) longshoremen (at each end of the trailer) and takes about 30 seconds. Four (4) longshoremen have been used for this task at some ports. Once the container has been loaded onto its trailer, it moves immediately away from the container unloading area to a staging area so that ship unloading can continue. The staging area is established by port authorities, but must be approved by the Captain of the Port.

The staging area is usually close to the container unloading area, on the port property, and may be an area where hazardous materials are routinely handled. It may be an indoor location, such as a warehouse. It is used for the conduct of any inspections or surveys that may be desired, to verify documentation received from the ship's captain, to verify marks and labels on the containers, to verify securement of the load, to assemble required documentation for the overland portion of the transport, and install or verify placards. (It should be noted that foreign origin shipments are prepared in accordance with International Atomic Energy Agency standards, which are generally compatible with NRC and the Department of Transportation regulations. In accordance with International Atomic Energy Agency regulations, containers usually are prepared with an oversized label, which is an International Atomic Energy Agency permitted substitute for placards. Even if placarded, the placards usually do not conform to the "Highway Route Controlled Quantity" placard used for these types of shipments in the United States. The overland portion of the transport leaves from this area. Inspections are described in Section D.4.4.

The National Defense Authorization Act for Fiscal Year 1994 requires that, to the extent practicable, casks containing spent nuclear fuel should be moved expeditiously from the port. However, infrequently, continuation of the transport may not occur immediately. This may be due to unplanned events such as severe weather, equipment breakdown or inspection discrepancy, or to planned actions such as queuing of the receipt of individual containers at the receiving site. If one or more containers must remain at the port, they are normally moved to a bonded warehouse, with the container remaining on its transporter. The warehouse is considered a secure area, and it typically meets the requirements of a "safe haven."

Specific handling for rail shipments depends upon the location of rail track with respect to the container handling crane "foot print." If the rail line is within the foot print, then containers are loaded directly onto the railcars and secured using International Standards Organization locks in the deck of the railcar. Typically, two containers are loaded onto each railcar. If the rail line is not in the foot print, then the container is loaded onto a dock container trailer and moved to the rail line. An industrial forklift is used to transfer the container to the railcar. Railcars may be moved by a switch engine, but more commonly, a railcar tugger is used.

For spent fuel shipments, the railcars carrying loaded containers are separated from each other by buffer cars. These cars are usually empty gondolas or flat cars. A caboose is usually provided for escorts and required security equipment. The buffer cars are selected so that the escorts can have a good view of the container cars. Containers mounted on container trailers are not shipped on the railcar in a "piggyback" configuration because of concerns related to the resulting high center of gravity.

D.4.3.1.2 Container Transfer Using Jib-Type Cranes

The port may not have a container crane and instead rely on a dockside, pedestal mounted, or ship installed, jib crane. Containers are moved using this type of crane by attaching a four-legged sling to the crane hook, and extending one leg of the sling to each of the four corners of the container. The sling must be manually attached to (and later removed from) the International Standards Organization fitting at the top of the corner posts of the container. The attachment and removal is done by two longshoremen, who must climb on top of the container.

The attachment of the sling can take as long as three minutes. The reason for this is that, typically, the longshoremen climb onto the container before the crane operator has positioned the crane and lower the sling for attachment. The longshoremen also provide hand signals to direct the positioning for the crane. Disconnecting the sling from the container is done more quickly, and it is usually not necessary to climb onto the top of the container. Two longshoremen usually lock the container to the container trailer and disconnect the sling, but sometimes four are used.

If the ship is equipped with a jib crane, it may also be used to remove containers. The process is the same as with a dock mounted crane, but the crane is operated by a member of the ships crew. Except for the operation of a ship mounted crane, members of the ships crew do not generally have a role in the unloading of the ship.

D.4.3.1.3 Roll-on/Roll-off Operations

In the roll-on/roll-off configuration the casks (either containerized, freestanding, or palletized) are already on the trailer that is used for overland transport. After unlashing, the trailer is moved to the staging area by a longshoreman using a dock tractor.

Unlashing of the trailer may involve up to four longshoremen, and require up to 5 minutes. Transfer of the trailer to the staging area can take as long as 15 minutes depending on the ship's hold and ramp conditions and the distance to the staging area. After the trailer is spotted in the staging area it is connected to the tractor that is used for over-the-road transport.

Since the trailer has not been available for inspection, if an inspection is required [other than that done by the tractor driver(s)], it is performed at the staging area. If the trailer is foreign owned, temporary apportioned motor vehicle tags are provided by the receiver or receivers' agent.

D.4.3.1.4 General Cargo Operations

Breakbulk operations could involve either a containerized or free standing cask. Typically, a free standing cask is mounted on a pallet to facilitate the handling of the cask using the cranes and winches commonly found on ships and at dock side. Handling of a containerized cask would follow the same operation described in Section D.4.3.1.1.

Breakbulk cargo handling of a free standing cask is more labor intensive, since the cask must be unlashed from the deck and may have to be moved using winches to a hatch opening. A crane is used to lift the cask out of the hold and onto the dock. Up to 4 longshoremen may be used to move the cask in the hold and attach crane rigging to the cask or pallet. Two (2) or more longshoremen may be required to complete the transfer to the dock. At the dock, the pallet is typically placed on a standard flat bed trailer and secured with chains or other binders. Total handling time is less if the cask is transported in the center of the hold, as it likely would be if a chartered vessel were used.

In general, breakbulk cargo requires the longest unloading times, compared to containerized freight and roll-on/roll-off configurations. While a good unloading time for general cargo is about 5 minutes per crane load, radioactive materials transfer can take as long as 20 minutes if the cask is not transported on a pallet and must be rigged separately.

Breakbulk shipment of free standing spent nuclear fuel casks is perceived to result in a somewhat less reliable tiedown of the cask to the deck of the vessel. There is also an increased risk of damage to the cask or its pallet due to the variability in lift fixtures on each pallet. For these reasons breakbulk shipments of spent fuel casks have not been routinely made since the mid 1970's. This mode of shipment is not expected to be routinely used for the transport of spent nuclear fuel, except as it would apply to the use of purpose-built ships.

D.4.3.2 Key Intermodal Tasks and Task Durations

This section summarizes the key intermodal handling tasks, and estimates the personnel requirements and task durations for the transfer of the casks from the vessel to the land conveyance. These summaries are based on the narratives presented previously. Actual handling times and resource requirements can be widely variable, depending in large degree upon the cask configuration, transport vessel, intermodal handling equipment, port practice, and specific procedures which could be implemented for a given shipment or shipping program.

Port inspections are described separately in Section D.4.4.

D.4.3.2.1 Intermodal Handling of Containerized Casks

Ports equipped for intermodal handling of containers have achieved average rates of transfer of general cargo containers between the vessel and dock of 45 per hour, or about one container each 80 seconds. This rate may not be achieved for containers carrying spent nuclear fuel. For conservatism, a transfer time of 2 minutes per container is assumed. Longer transfer times would be expected if the port is not equipped with container cranes. A transfer time of 3 minutes is assumed if jib or boom type cranes are used with slings to lift the containers. Containers are assumed to be installed on the container trailer which would be used in over-the-road transport.

Port practices, such as union rules and safety procedures, would dictate the number of personnel used to unlash, transfer, and lash the container to its transporter. Consequently, the number of personnel required for each task could vary slightly between ports.

Each shipment, consisting of one or more containers, is expected to be observed by one or more persons who represent various interests in the shipment. These observers would have no active role in the transfer of the container, and would be expected to be 9.1 m (30 ft) or more away from the container.

Vessel crew members do not normally participate in container transfer operations, except for a member having responsibility for the cargo. Only this individual is considered to be present during transfer, stationed at the vessel hatch.

Table D-8 summarizes the handling of a container on a container ship. All of the distances are assumed to be from the container surface, or the projected container surface if an open container is used. There are no tasks which require contact with the cask surface.

Table D-8 Container Transfer Summary

Task / *Personnel/Location*	*Unlash Cargo*	*Attach to Crane*[a]	*Transfer to Dock*	*Lash to Transporter*	*Move to Staging*
0-.9 m (0-3 ft)	2 - 4[a,b]	1[b]	-	2 - 4[b]	-
duration (min)	0.25	0.5	-	0.25	-
1.5-3 m(5-10 ft)	-	-		-	-
duration (min)		-	-	-	-
3-6 m (10-20 ft)	-	-	-	1[c]	1[c]
duration (min)	-	-	-	0.25	3
6-9 m (20-30 ft)	1[b]	2[d]	1[d]	1[d]	-
duration (min)	0.25	0.5	1	0.1	-
9 m (30 ft)	1[e]	1[e]	1[e]	4[f]	4[f]
duration (min)	0.25	0.5	0.1	0.25	0.25

[a]*Crane attachment to containers is automated.*

[b]*longshoremen*

[c]*truck driver*

[d]*crane operator*

[e]*ships crew*

[f]*observer*

Containerized casks could be shipped aboard container or general cargo vessels. No significant difference in transfer times is expected between these vessel types.

D.4.3.2.2 Intermodal Handling of Roll-on, Roll-off Casks

Casks in a roll-on/roll-off configuration, either containerized or palletized are assumed to be transported on a roll-on/roll-off vessel and received at a port equipped to support roll-on/roll-off operations. Assumptions regarding port practices, observers and crew members are the same as those made for containerized or palletized cask transfer.

Removal of the trailered cask from the vessel is assumed to be done using a port tractor. Attachment of the trailer to the tractor which would be used for over-the-road transport must be done in the freight ready area, or the staging area.

All of the distances are assumed to be from the trailer or personnel barrier surface, or the projected trailer surface if there is no personnel barrier. There are no tasks which require contact with the cask surface.

Table D-9 summarizes the cask unloading and transfer activities for a roll-on/roll-off cargo vessel.

Transfer of roll-on/roll-off configured casks is not expected to occur on vessels not equipped with a ramp. Consequently, lifting of the trailered cask by crane is not expected to occur.

Table D-9 Roll-on/Roll-off Cask Transfer Summary

Task / *Personnel/Location*	*Unlash Cargo*	*Attach to Crane*	*Transfer to Dock*	*Lash to Transporter*	*Move to Staging*
0-.9 m (0-3 ft)	4[a]	2[a]	-	4[a]	-
duration (min)	4	0.5	-	0.5	-
1.5-3 m (5-10 ft)	-	-	1[b]	-	-
duration (min)	-	-	0.25	-	-
3-6 m (10-20 ft)	1[a]	1[b]	1[b]	2[b]	1[b]
duration (min)	4	0.5	2	0.5	3
6-9 m (20-30 ft)	1[c]	1[c]	1[c]	-	-
duration (min)	4	0.5	0.25	-	-
9 m (30 ft)	-	-	-	4[d]	4[d]
duration (min)	-	-	-	0.5	0.25

[a] *longshoremen*

[b] *truck driver*

[c] *ships crew*

[d] *observer*

D.4.3.2.3 Intermodal Handling of Free-Standing (Palletized) Casks

As previously noted, casks are expected to be mounted on a skid, cradle or pallet ("pallet") to facilitate handling, lifting, and stowage. Transfer of these casks is usually somewhat more labor intensive than handling containerized casks, since the pallets are not standardized. The pallets are usually uniquely designed to accommodate a specific cask. Consequently, more effort is usually required to secure the cask in stowage, and to install lift slings for transfer. In addition, some care is needed to ensure that lifting and handling operations do not damage the cask.

Assumptions regarding port practices, observers, and crew members are the same as those made for containerized cask transfer.

It is assumed that the palletized cask would be installed on a flat bed trailer not necessarily having the tiedown fixtures required to secure the pallet. Some additional effort is expected to be required to secure the pallet to a trailer, compared to that required for containerized casks. However, it is assumed that the pallet is placed on the trailer that would be used for over-the-road transport so that no subsequent transfer of the pallet is needed.

Table D-10 summarizes the palletized cask unloading and transfer activities for a breakbulk cargo vessel. Distances are from the edge of the pallet, or its projected edge. There are no tasks which require contact with the cask surface.

D.4.4 Port Inspection Activities

There are several agencies, both Federal and State that could make an inspection of the cargo at any point from when the vessel docked while the cargo is still on board, until the cargo reaches its final resting place in the facility. The U.S. Coast Guard has recently designated personnel to inspect hazardous cargoes, specifically containers laden with hazardous cargo. The U.S. Coast Guard, however, has no current programs in place for the training of inspectors of radioactive materials. This may change in the near future. The U.S. Coast Guard does have an aggressive program for container inspection and compliance. The U.S. Coast Guard would perform an inspection on the vessel, including all documentation (bills of

Table D-10 Palletized Cask Transfer Summary

Task / Personnel/Location	Unlash Cargo	Move to Hatch[a]	Attach to Crane	Transfer to Dock	Lash[b] to Transporter	Move to Staging
0-.9 m (0-3 ft)	4[c]	0 - 4[c]	2[c]	-	4[c]	-
duration (min)	4	0 - 5	0.5	-	4	-
1.5-3 m (5-10 ft)	-	-	-	-	-	-
duration (min)	-	-	-	-	-	-
3-6 m (10-20 ft)	-	-	-	-	-	1[d]
duration (min)	-	-	-	-	-	3
6-9 m (20-30 ft)	2[c,e]	0 - 2[c,e]	2[c,e]	1[c,e]	4[c,e]	4[f]
duration (min)	4	0 - 5	0.5	0.1	4	0.25
9 m (30 ft)	-	-	1[g]	1[g]	1[g]	-
duration (min)	-	-	0.5	2	0.5	-

[a]*this task is not required if the cask is in the center of the ships hold*

[b]*transporter is to be used for over-the-road transport*

[c]*longshoremen*

[d]*truck driver*

[e]*ships crew*

[f]*observer*

[g]*crane operator*

lading and dangerous cargo manifests) and container placarding. Once the cargo is off-loaded, NRC may require an inspection of the container or cask and perform a radiation survey. Also, state agencies that are designated with such responsibilities as safety and transportation may require an inspection, especially on the tractor and semi-trailer transporting the casks. These latter inspections could take place dockside, at the facility, at a staging area, or at the gate area of the port. It is also possible that there would not be any inspections made by any agency.

The principal kinds of inspections that normally occur are: (1) verification of container (or cask) marks and labels to the accompanying documentation; (2) verification of radiation readings around the container (or cask); and (3) inspection of the transport vehicle, typically a tractor-trailer rig. Other inspections, such as condition of a container, can also be performed. Most of the inspections performed are done at the staging area, although inspection on the ship is also possible.

Port inspections are discretionary in that there is no regulatory requirement that they be performed by any party, with two exceptions. One exception is that a radiation survey map must be prepared for overland transport by truck and rail. This map must show the radiation levels at 2 m (6.6 ft) from the container or cask, and it must show the radiation level in the truck normally occupied by the driver. The agent for the receiver normally completes this map. A second exception is that State laws may require a permit for the transport of the spent fuel. Typically, this permit requires an inspection of the transporter for road worthiness, and sometimes a review of other documents. Inspections of railcars are normally not done by state inspectors. The performance of additional inspections may be established by (local) policy, procedures, or preference. In this context, inspections may occur more than once. The reason for this is that Federal agencies, such as the Department of Transportation and the U.S. Coast Guard, and the States (and the port authority), have a right of inspection. For any given shipment or individual cask, those agencies may not be represented, and even if represented, the right of inspection may not be exercised.

The representative of the receiver normally verifies that the marks and labels of the container conform to the documentation supplied by the shipper, that radiation levels are within U.S. regulatory limits, and that they conform to the radiation survey documents supplied with the shipping papers. These verifications are usually made after the container is removed from the ship and is in place on its transporter. Surveys of the container can also be performed aboard ship. This may be done for example, if there was a belief that actual radiation readings could be higher than those reported in the shipment documentation because of some event that occurred in transit, or for information.

Inspections of the transport equipment may be required by the State. These inspections are normally done prior to loading of the container on the bed of the trailer or railcar. This ensures that the container is loaded on an acceptable transporter. There is no radiation exposure which is attributable to this inspection. Verification of container tiedown is performed by the truck driver, or rail crew, as required by current regulations. Typically, tiedowns are also verified by a representative of the consignee. Tasks and personnel requirements are summarized in Table D-11.

Table D-11 Summary of Inspection Tasks and Personnel Requirements Per Container[a]

		Federal Agencies[b]			*State*	*Local/Port*	*Receiver*
		USCG	*DOT*	*NRC*			
Container	Personnel	1	1	1	1	1	1
	Time (min)	5	2	2	2	5	5
Roll-on/Roll-off	Personnel	1	1[c]	1	1[c]	1	1
	Time (min)	2	15	10	15	5	5
Breakbulk	Personnel	1	1[c]	1	1[c]	1	1
	Time (min)	2	15	10	15	5	5

[a]*Personnel expected to be within 3 m (10 ft) of the container.*

[b]*Discretionary inspections which may be performed; USCG = U.S. Coast Guard, DOT = Department of Transportation.*

[c]*Includes trailer inspection.*

D.4.5 Port Worker Incident-Free Analysis Methodology

Incident-free impacts of the offloading of foreign research reactor spent nuclear fuel have been estimated for port workers, inspectors, and observers of the activity. It has been assumed that no member of the public, other than the above-mentioned workers, would be present at the port during offloading. Ports tend to be relatively large areas with little or no access by the general public. Impacts of the incident-free shipment of foreign research reactor spent nuclear fuel on the general public would not be expected until the shipment leaves the port area. It has also been assumed that all foreign research reactor spent nuclear fuel would be shipped in containers, regardless of whether transport occurs via container or general cargo vessels.

Once a shipment arrives in port, the spent nuclear fuel packages would be inspected by customs officials, U.S. Coast Guard personnel, port officials, etc. Up to six inspections performed by Federal, State, and local agencies, and the shipping agent are assumed to occur for each cask shipment. The durations of these inspections are provided in Table D-11. The assumption is made that the container is opened only for the inspection conducted when the cask is first off-loaded from the vessel.

In addition to the personnel involved in the inspections, there are other port workers (longshoremen, port officials, security personnel, etc.) who would be directly involved in or co-located near the off-loading of the container, its securing to the tractor-trailer, and in the movement of the container to a staging area. (The incident-free impact of offloading operations on the ship's crew were addressed in the marine impact analysis presented in Appendix C). While arrangements are expected to be made for the immediate departure of the spent nuclear fuel from the port of entry, it is recognized that situations could occur where there may be some delay in departing the port. For example, these delays could be caused by weather or road conditions. A delay of up to 24 hours is assumed for all shipments. To account for the impact of these delays, the dose to workers not directly involved in offloading activities was estimated. In addition to workers identified in Tables D-8 through D-9, it was assumed that 50 workers are exposed to the cask for 8 hours at a distance of 50 m (163 ft). This provides a dose estimate for the 24-hour storage period.

These dose estimates are independent of port location or type. Two types of cargo vessels have been addressed in the analysis, encompassing the range of times required for offloading activities. Container vessels required the least amount of time to offload; breakbulk vessels the longest. It has been assumed that offloading operations for both containerized breakbulk cargo and container cargo at all potential ports of entry is similar. These estimates are intended to bound the potential doses associated with port activities. As discussed above, breakbulk transport of the containerized fuel casks are expected to result in the largest dose to workers due to port operations due to the longer times associated with activities that bring workers into proximity of the casks.

External radiation for an intact shipping package must be below specified limits that control the exposure of the handling personnel and general public. These limits are set forth in 49 CFR 173.

The limit of interest established therein is a limit of 10 mrem per hour at any point 2 m (6.6 ft) from the vertical planes projected by the outer lateral surfaces of the transport vehicle. This limit is associated with an "exclusive-use" shipment, that is one in which no other cargo is loaded in the container used for the spent fuel transportation casks, not that the ship is an exclusive use vessel. All shipments within this program would be expected to fall within this category. In general, much of the foreign research reactor spent nuclear fuel potentially to be received would have cooled for a significant amount of time prior to shipment, resulting in external dose rates much less than the regulatory limit. Shipments of research reactor fuel in the past have had doses averaging approximately 2.3 mrem per hour at 1 m (3.3 ft) from the cask surface (see Section F.5 of Appendix F). Due to the scope of this program and the possibility that some of the fuel could be shipped fresher than has been done previously, the above cited regulatory limit has been used to estimate the worker exposures for all shipments. Appendix F, Section F.5, provides exposure rate versus distance for a transportation cask that is loaded with spent fuel that results in a dose rate at 2 m (6.6 ft) of 10 mrem per hour. This relationship was used to assign dose rates for the port activities.

Table D-12 and D-13 describe the types and numbers of personnel involved in the port activities associated with offloading the spent nuclear fuel. The times, distances, and maximum doses associated with these activities are listed for each type of personnel (all doses are simply the product of the dose rate to which the worker is exposed, based upon distance from the transportation cask, and the time the worker is exposed to this dose rate). The total port worker population and the maximally exposed individual doses are also provided. During incident-free port operations, the highest individual exposure would be to handlers and inspectors of the casks. Exposures are port-independent since it is assumed that operations would be similar at any of the potential or alternative ports of entry.

Table D-12 Port Worker Consequences from Shipment of Foreign Research Reactor Spent Nuclear Fuel on Breakbulk Vessels

Exposed Workers	*Exposure Distance (m)*	*Dose Rate (mrem/hr)*	*Exposure Time (minutes/cask)*	*Dose/Person/ Cask (mrem)*	*Exposed Workers*	*Collective Dose (Person-rem)*	*Individual Risk (LCF)*	*Collective Risk (LCF)*
Longshoreman A1	0.50	37[b]	0.25	0.15	2	0.00031	6.2E-08	1.2E-07
Longshoreman A2	0.50	37[b]	3.3	2.0	2	0.0040	8.0E-07	1.6E-06
Longshoreman A3	6.00	6.4[b]	0.25	0.027	1	0.000027	1.1E-08	1.1E-08
Longshoreman B1	0.50	34	1.0	0.57	4	0.0023	2.3E-07	9.1E-07
Maximum				2.0[a]			8.0E-07a	
Subtotal						0.0066		2.6E-06
Crane Operator 1	9.00	1.8	3.0	0.090	1	0.00009	3.6E-08	3.6E-08
Maximum				0.090[a]			3.6E-08[a]	
Subtotal						0.00009		3.6E-08
Truck Driver	3.00	7.1	3.0	0.36	1	0.00036	1.4E-07	1.4E-07
Maximum				0.36[a]			1.4E-07[a]	
Subtotal						0.00036		1.4E-07
Observers	6.00	3.2	0.25	0.013	4	0.000053	5.3E-09	2.1E-08
Observers	50	0.01	480	0.0802	50	0.0040	3.2E-08	1.6E-06
Maximum				0.080[a]			3.2E-08[a]	
Subtotal						0.0041		1.6E-06
USCG Inspector	1.5	15	2.0	0.5	1	0.00050	2.0E-07	2.0E-07
DOT Inspector	1.5	15	15	3.8	1	0.0038	1.5E-06	1.5E-06
NRC Inspector	1.5	15	10	2.5	1	0.0025	1.0E-06	1.0E-06
State Inspector	1.5	15	15	3.8	1	0.0038	1.5E-06	1.5E-06
Local/Port Inspector	1.5	15	5	1.3	1	0.0013	5.0E-07	5.0E-07
Receiver	1.5	15	5	1.3	1	0.0013	5.0E-07	5.0E-07
Maximum				3.8[a]			1.5E-06[a]	
Subtotal						0.013		5.2E-06
Maximum				3.8[a]			1.5E-06[a]	
Total						**0.024**		**9.6E-06**

[a] *Maximum individual exposure/risk.*

[b] *Includes dose from second cask in hold.*

USCG = U.S. Coast Guard, DOT = Department of Transportation

Table D-12 was developed using the information pertaining to the offloading of containerized foreign research reactor spent nuclear fuel from a breakbulk vessel. The exposure times and the distances from the transportation cask used to develop the dose estimates were derived from Table D-8 and assuming the longer transfer times associated with jib or boom cranes. The exposures (worker doses) resulting from the offloading activities associated with this type of vessel are the highest, on a per cask basis, of the three types of vessels considered for transport of the foreign research reactor spent nuclear fuel: breakbulk, container, and roll-on/roll-off (the chartered or purpose-built ship could conceivably be of any of these designs). Therefore, the dose estimates derived from this data provide the upper limit to the doses that could be calculated for the offloading activities.

Alternatively, the worker doses resulting from the offloading of a foreign research reactor spent nuclear fuel cask from a container vessel result in the lowest doses per cask of the types of vessels considered for use in the shipment of the foreign research reactor spent nuclear fuel. Table D-13 was developed using the exposure times and the distances from the transportation cask developed for a container vessel which are provided in Table D-8.

Table D-13 Port Worker Consequences from Shipment of Foreign Research Reactor Spent Nuclear Fuel on Containerized Vessels

Exposed Workers	Exposure Distance (m)	Dose Rate (mrem/hr)	Exposure Time (minutes/cask)	Dose/Person/Cask (mrem)	Exposed Workers	Collective Dose (Person-rem)	Individual Risk (LCF)	Collective Risk (LCF)
Longshoreman A1	0.50	37[a]	0.25	0.15	3	0.00046	6.2E-08	1.9E-07
Longshoreman A2	0.50	37[a]	0.75	0.46	1	0.00046	1.9E-07	1.9E-07
Longshoreman A3	6.00	6.4[a]	0.25	0.027	1	0.000027	1.1E-08	1.1E-08
Longshoreman B1	0.50	34	0.25	0.14	4	0.00057	5.7E-08	2.3E-07
Maximum				0.46[a]			1.9E-07[a]	
Subtotal						0.0015		6.1E-07
Crane Operator 1	6.00	32	0.50	0.027	1	0.000027	1.1E-08	1.1E-08
Crane Operator 2	6.00	32	1.6	0.085	1	0.000085	3.4E-08	3.4E-08
Maximum				0.085[a]			3.4E-08a	
Subtotal						0.00011		4.5E-08
Truck Driver	3.00	7.1	3.3	0.38	1	0.00038	1.5E-07	1.5E-07
Maximum				0.38[a]			1.5E-07[a]	
Subtotal						0.00038		1.5E-07
Observers	6.00	3.2	0.5	0.027	4	0.00011	1.1E-08	4.3E-08
Observers	50	0.01	480	0.080	50	0.0040	3.2E-08	1.6E-06
Maximum				0.080[a]			3.2E-08[a]	
Subtotal						0.0041		1.6E-06
USCG Inspector	1.5	15	5.0	1.3	1	0.0013	5.0E-07	5.0E-07
DOT Inspector	1.5	15	2.0	0.5	1	0.00050	2.0E-07	2.0E-07
NRC Inspector	1.5	15	2.0	0.5	1	0.00050	2.0E-07	2.0E-07
State Inspector	1.5	15	2.0	0.5	1	0.00050	2.0E-07	2.0E-07
Local/Port Inspector	1.5	15	5.0	1.3	1	0.0013	5.0E-07	5.0E-07
Receiver	1.5	15	5.0	1.3	1	0.0013	5.0E-07	2.0E-07
Maximum				1.3[a]			5.0E-07[a]	
Subtotal						0.0053		2.1E-06
Maximum				1.3[a]			5.0E-07[a]	
Total						**0.011**		**4.6E-06**

[a] *Maximum individual exposure/risk.*

[b] *Includes dose from second cask in hold.*

USCG = U.S. Coast Guard, DOT = Department of Transportation

In both of these cases it was assumed that two transportation casks were being shipped on a single vessel and the two casks were both in the same hold. By making this assumption, the dose to the workers in the ship's hold is the result of exposure to two radiation fields during the offloading of the first casks. The impact of the presence of the second transportation cask has been included in the dose rates for the longshoremen who are in the ship's hold during the offloading activity. To simplify the analysis, it has been assumed that the dose rates for the offloading of the two casks are the same (i.e., even though when the second cask is being offloaded there is only one transportation cask in the hold, the exposures are calculated assuming that there are two casks in the hold). The total number of transportation casks shipped on a single vessel would not impact the results of this analysis. The per shipment results are for the shipment of a single cask, assuming two casks per hold. Annual exposures and exposures for the entire program do not depend on the number of transportation casks per shipment. Under the assumption that a vessel carrying more than two casks would be loaded two casks per hold, these results are solely dependent on the number of cask shipments per year and the total number of cask shipments.

There is approximately a factor of two difference between the total worker dose resulting from the use of a breakbulk vessel and the use of a container vessel per transportation cask. There is a larger difference between the dose to the maximally exposed individual (MEI). The MEI for the breakbulk vessel receives a dose of 3.8 mrem per transportation cask offloading while for the offloading of a transportation cask from a container vessel the MEI receives a dose of 1.3 mrem.

Another consideration that could affect the total worker exposure is the possibility that the vessel transporting the foreign research reactor spent nuclear fuel could make intermediate port calls between the foreign port at which the transportation cask is loaded and the port of entry for the foreign research reactor spent nuclear fuel. At the intermediate ports of call, it is possible that cargo being shipped on the vessel and in the same hold as the transportation casks could be loaded/offloaded or moved. The analysis was expanded to consider the impacts on port workers at these intermediate ports. Table D-14 provides the information used to estimate the dose to the port workers in intermediate ports. The estimates consider that the hold in which the transportation casks are being stowed have been fully loaded and that all of the cargo in the vicinity of the transportation casks must be moved at one of the intermediate ports of call. The vessel assumed in the intermediate port analysis was a breakbulk vessel. As in the analysis of the impact of the offloading of the transportation casks, this assumption results in calculations based on the type of vessel that will result in the largest estimated impact on the port workers.

Table D-14 Port Worker Exposure - Each Intermediate Port

Exposed Workers	*Distance (m)*	*Dose Rate[a] (mrem/hr)*	*Exposure Time (minutes)*	*Dose/Person (mrem)*	*Number of Workers[b]*	*Collective Dose (person-rem)*	*Individual Risk (LCF)*	*Risk per Port Call (LCF)*
Longshoreman	1.5	18	5	1.5	4	--	--	--
	5	6.4	6	0.64	4	--	--	--
	8	4.6	1	0.08	4	--	--	--
Total				**2.2**	**4**	**0.0089**	**0.00000089**	**0.0000035**

[a]*The dose rate includes the dose rate from two casks stored in the same hold.*

[b]*The same four workers are assumed to receive the entire dose from cargo handling activities in each intermediate port stop.*

The per shipment data provided in Tables D-12 through D-14 was used to develop estimates of the incident-free impact of the marine shipment of 721 transportation casks on port workers. (The number of shipments required is derived in Appendix B. The 721 shipments used in this portion of the analysis exclude all shipments of Canadian origin which are expected to be overland shipments). Table D-15 provides the results of this analysis. Data is provided for two possible shipment conditions. In the first a breakbulk vessel is used to transport all of the foreign research reactor spent nuclear fuel and this vessel is assumed to make two intermediate port calls on every voyage. During these intermediate port calls the cargo in the same hold as the transportation casks is assumed to be moved (loaded and/or offloaded) twice. The impact on port workers, in terms of population exposure and risk, in the intermediate ports is therefore twice the impact presented in Table D-14. The second set of assumptions used is that all shipments are made on a container vessel that does not make intermediate port calls. These assumptions result in a lower estimate of port worker risk since the impact of intermediate port calls is eliminated and the offloading activities for a container vessel result in lower overall doses to the port workers. These two sets of assumptions, therefore, provide estimates of the range of potential impacts on port workers.

In calculating the MEI, it was necessary to estimate the number of shipments to which a single worker could be exposed. Using the information in Table C-1, the shipments of foreign research reactor spent nuclear fuel were divided into eastern and western shipments. The eastern shipments are those that would

Table D-15 Integrated Port Worker Dose for the Basic Implementation of Management Alternative 1

	Breakbulk Vessel with 2 Intermediate Port Calls				*Container Vessel - No Intermediate Port Calls*			
	Maximally Exposed Individual (rem)	*Collective Dose to Workers (person-rem)*	*MEI Risk (LCF)*	*Worker Risk LCF)*	*Maximally Exposed Individual (rem)*	*Collective Dose to Workers (person-rem)*	*MEI Risk (LCF)*	*Worker Risk (LCF)*
Inspectors	2.0[a]	9.4	0.00080	0.0037	0.67	3.8	0.00027	0.0015
Port Handlers - Intermediate Ports	1.2	13	0.00047	0.0051	----	----	----	----
Port Handlers - Port of Entry	1.1	4.8	0.00043	0.009	0.25	1.1	0.00010	0.00044
Port Staging Personnel	0.19	3.2	0.000076	0.0013	0.21	3.3	0.00008	0.0013
Total	----	**30.2**	----	**0.012**	----	**8.2**	----	**0.0033**
Maximum	**2.0[a]**	----	**0.00080**	----	**0.67**	----	**0.00027**	----

[a]*This dose is above the allowed limit of 100 mrem/yr for the general population and would be mitigated to below the limit.*

be expected to be shipped to a port on the East Coast of the United States if the shortest shipping distance were used. Western shipments are those that would be shipped to the West Coast port. From Table C-1, 535 shipments would be considered East Coast shipments; 186 West Coast. In determining the MEI, it was assumed that all of these East Coast shipments were made through the same port, and the same workers were involved in the offloading of the transportation casks for all shipments.

The total impact on the worker population was determined by using the full 721 transportation cask shipments. Both the MEI and the collective dose to the workers have been converted into a risk estimate of LCF resulting from the doses received in offloading the transportation casks loaded with foreign research reactor spent nuclear fuel. The range of impacts for the program is from 8.2 person-rem (0.0033 LCF) (for the use of container vessels with no intermediate port calls) to 30 person-rem (0.012 LCF) (for the use of breakbulk vessels with two intermediate port calls). These risks imply that there is between a three-in-a-thousand and a one-in-a-hundred chance that this program will result in one LCF as a result of the incident-free impact on port workers. The relationship between worker dose and cancer fatalities is that 1 rem is equivalent to 0.0004 LCF.

Under the basic implementation of Management Alternative 1, shipments would be received over a 13-year period, the 10-year period for spent nuclear fuel generation plus 3 additional years to allow for the coordination of available storage, transportation casks, shipping arrangements, etc. Assuming that the shipments were evenly distributed over the 13-year period, the doses to the MEI could be in excess of the DOE and NRC limits for doses to the general public (100 mrem per year). If breakbulk vessels were used, the MEI would receive approximately 150 mrem per year on average, if no mitigation steps were taken. If container vessels were used, no individuals are expected to receive a dose in excess of the public dose limits.

The above calculations were all performed assuming that every transportation cask was shipped with an external dose rate at the selected exclusive use regulatory limit of 10 mrem hour at 2 m (6.6 ft) from the surface of the container. This provides an estimate of the upper limit to what the incident-free impacts of the offloading of the transportation casks could be. To determine a more realistic estimate of these impacts, the analysis was redone using historical data on the external dose rates associated with the transportation of research reactor spent nuclear fuel. This analysis results in an average dose rate of approximately 2.3 mrem per hour at 1 m (3.3 ft) from the cask surface, which is equivalent to a dose rate of 1 mrem per hour at 2 m (6.6 ft) from the cask surface. If the added distance from the cask surface to the container surface is not credited, this dose rate is one-tenth of the dose rate derived from the "exclusive use" regulatory limit. (See Appendix F, Section F.5)

Tables D-16 through D-19 provide the results of this analysis. No other assumptions were modified between this analysis from those used to develop the data presented earlier in this section. All of the results using the "historical" data are an order-of-magnitude lower than results derived from the use of the regulatory limit dose rates.

Table D-16 Port Worker Consequences from Shipment of Foreign Research Reactor Spent Nuclear Fuel on Breakbulk Vessels (Historical Data)

Exposed Workers	*Exposure Distance (m)*	*Dose Rate (mrem/hr)*	*Exposure Time (minutes/cask)*	*Dose/ Person/Cask (mrem)*	*Exposed Workers*	*Collective Dose (Person-rem)*	*Individual Risk (LCF)*	*Collective Risk (LCF)*
Longshoreman A1	0.50	3.7[b]	0.25	0.015	2	3.1E-05	6.2E-09	1.2E-08
Longshoreman A2	0.50	3.7[b]	3.3	0.20	2	4.0E-04	8.0E-08	1.6E-07
Longshoreman A3	6.00	0.64[b]	0.25	0.0027	1	2.7E-06	1.1E-09	1.1E-09
Longshoreman B1	0.50	34	1.0	0.057	4	2.3E-04	2.3E-08	9.1E-08
Maximum				0.20[a]			8.0E-08a	
Subtotal						6.6E-04		2.6E-07
Crane Operator 1	9.00	0.18	3.0	0.009	1	9.0E-06	3.6E-09	3.6E-09
Maximum				0.009[a]			3.6 E-09[a]	
Subtotal						9.0E-06		3.6E-09
Truck Driver	3.00	0.71	3.0	0.036	1	3.6E-05	1.4E-08	1.4E-08
Maximum				0.036[a]			1.4E-08[a]	
Subtotal						3.6E-05		1.4E-08
Observers	6.00	0.32	0.25	0.0013	4	5.3E-06	5.3E-10	2.1E-09
Observers	50	0.001	480	0.008	50	4.0E-04	3.2E-09	1.6E-07
Maximum				0.008[a]			3.2E-09[a]	
Subtotal						4.1E-04		1.6E-07
USCG Inspector	1.5	1.5	2.0	0.05	1	5.0E-05	2.0E-08	2.0E-08
DOT Inspector	1.5	1.5	15	0.38	1	3.8E-04	1.5E-07	1.5E-07
NRC Inspector	1.5	1.5	10	0.25	1	2.5E-04	1.0E-07	1.0E-07
State Inspector	1.5	1.5	15	0.38	1	3.8E-04	1 .5E-07	1.5E-07
Local/Port Inspector	1.5	1.5	5	0.13	1	1.3E-04	5.0E-08	5.0E-08
Receiver	1.5	1.5	5	0.13	1	1.3E-04	5.0E-08	5.0E-08
Maximum				0.38			1.5E-07	
Subtotal						1.3E-03		5.2E-07
Maximum				0.38[a]			1.5E-07[a]	
Total						**2.4E-03**		**9.6E-07**

[a]*Maximum individual exposure/risk.*

[b]*Includes dose from second cask in hold.*

USCG = U.S. Coast Guard, DOT = Department of Transportation

The total population dose (dose to the port workers) ranges from 3.0 person-rem (breakbulk vessel with two intermediate port calls) and 0.7 person-rem (container vessel with no intermediate port calls). This corresponds to a risk of 0.0012 to 0.00033 LCF, that is, a one-in-a-thousand to a one-in-three thousand chance of incurring one LCF. For a population of workers, the relationship between exposure and LCF is

Table D-17 Port Worker Consequences from Shipment of Foreign Research Reactor Spent Nuclear Fuel on Containerized Vessels (Historical Data)

Exposed Workers	Exposure Distance (m)	Dose Rate (mrem/hr)	Exposure Time (minutes/cask)	Dose/Person/Cask (mrem)	Exposed Workers	Collective Dose (Person-rem)	Individual Risk (LCF)	Collective Risk (LCF)
Longshoreman A1	0.50	3.7[a]	0.25	0.015	3	4.6E-05	6.2E-09	1.9E-08
Longshoreman A2	0.50	3.7[b]	0.75	0.046	1	4.6E-05	1.9E-08	1.9E-08
Longshoreman A3	6.00	0.64[b]	0.25	0.0027	1	2.7E-06	1.1E-09	1.1E-09
Longshoreman B1	0.50	340	0.25	0.014	4	5.7E-05	5.7E-08	2.3E-08
Maximum				0.046[a]			1.9E-08[a]	
Subtotal						1.5E-04		6.1E-08
Crane Operator 1	6.00	0.32	0.5	0.0027	1	2.7E-06	1.1E-09	1.1E-09
Crane Operator 2	6.00	0.32	1.6	0.0085	1	8.5E-06	3.4E-09	3.4E-09
Maximum				0.0085[a]			3.4E-09[a]	
Subtotal						1.1E-05		4.5E-09
Truck Driver	3.00	0.71	3.3	0.038	1	3.8E-05	1.5E-08	1.5E-08
Maximum				0.038[a]			1.5E-08[a]	
Subtotal						3.8E-05		1.5E-08
Observers	6.00	0.32	0.5	0.0027	4	1.1E-05	1.1E-09	4.3E-09
Observers	50	0.001	480	0.0080	50	4.0E-04	3.2E-09	1.6E-07
Maximum				0.0080[a]			3.2E-09[a]	
Subtotal						4.1E-04		1.6E-07
USCG Inspector	1.5	1.5	0.5	0.13	1	1.3E-04	5.0E-08	5.0E-08
DOT Inspector	1.5	1.5	0.2	0.050	1	5.0E-05	2.0E-08	2.0E-08
NRC Inspector	1.5	1.5	0.2	0.050	1	5.0E-05	2.0E-08	2.0E-08
State Inspector	1.5	1.5	0.2	0.050	1	5.0E-05	2.0E-08	2.0E-08
Local/Port Inspector	1.5	1.5	0.5	0.013	1	1.3E-04	5.0E-08	5.0E-08
Receiver	1.5	1.5	0.5	0.13	1	1.3E-04	5.0E-08	5.0E-08
Maximum				0.13[a]			5.0E-08[a]	
Subtotal						5.3E-04		2.1E-07
Maximum				0.13[a]			5.0E-08[a]	
Total						**1.1E-03**		**4.5E-07**

[a]*Maximum individual exposure/risk.*

[b]*Includes dose from second cask in hold.*

USCG = U.S. Coast Guard, DOT = Department of Transportation

Table D-18 Port Worker Exposure - Intermediate Ports (Historical Cask External Dose Rate Data)

Exposed Workers	Distance (m)	Dose Rate[a] (mrem/hr)	Exposure Time (minutes)	Dose/Person (mrem)	Number of Workers[b]	Collective Dose (person-rem)	Individual Risk (LCF)	Risk per Port Call (LCF)
Longshoreman	1.5	1.8	5	0.15	4	--	--	--
	5	0.6	6	0.06	4			--
	8	0.5	1	0.01	4	--	--	--
Total				**0.22**	**4**	**0.00089**	**0.000000089**	**0.00000035**

[a]*The dose rate includes the dose rate from two casks stored in the same hold.*

[b]*The same four workers are assumed to receive the entire dose from cargo handling activities in each intermediate port stop.*

Table D-19 Integrated Port Worker Dose for the Basic Implementation of Management Alternative 1 (Historical Cask Dose Rates)

	Breakbulk Vessel with 2 Intermediate Port Calls				*Container Vessel - No Intermediate Port Calls*			
	Maximally Exposed Individual (rem)	*Collective Dose (person-rem)*	*MEI Risk (LCF)*	*Risk (LCF)*	*Maximally Exposed Individual (rem)*	*Collective Dose (person-rem)*	*MEI Risk (LCF)*	*Risk (LCF)*
Inspectors	0.20	0.94	0.00008	0.00037	0.07	0.38	0.00002	0.00015
Port Handlers - Intermediate Ports	0.12	1.3	0.000047	0.00051	----	----	----	----
Port Handlers - Port of Entry	0.11	0.5	0.000043	0.00019	0.03	0.11	0.000010	0.000044
Port Staging Personnel	0.02	0.3	0.000008	0.00013	0.02	0.33	0.000009	0.00013
Maximum	0.20[a]		0.00008[a]		0.07[a]		0.000027[a]	
Total		**3.0**		**0.0012**		**0.8**		**0.00033**

[a]*Maximally exposed individual.*

1 rem is equivalent to 0.0004 LCF. The MEI would receive a dose of 0.2 rem over the 13-year period of the basic implementation of Management Alternative 1. This is approximately 15 mrem per year, which is well below the NRC and DOE limits for exposure to the public (100 mrem per year).

The results of these analyses indicate that some of the port personnel that handle and inspect foreign research reactor spent nuclear fuel shipping containers could receive doses that exceed public exposure limits established by DOE and the NRC, especially when the dose rate from the casks are assumed to be at the regulatory limit for exclusive use shipments of 10 mrem per hour measured 2 m (6.6 ft) from the surface of the shipping container. The analyses results are conservative due to three factors. First, it is estimated that for most shipments the external dose rate for the loaded transportation cask would be near the historic dose rates, which average a factor of ten below the regulatory limit. Second, the analyses assumed that the same port inspectors and handlers handle all shipments. In reality, most port personnel work on shifts, so the likelihood of all shipments being handled by the same shift is low. Finally, all of the shipments passing through any East Coast port were assumed to pass through the same port. In reality, it is more than likely that the shipments would be made through more than a single port.

However, the existence of some shipments with external dose rates closer to the exclusive use regulatory limit suggests that DOE should provide a means to assure that individual port personnel do not receive doses in excess of the public dose limits. As a minimum, the program should establish administrative procedures that would maintain records of the exposure rates associated with each shipment and the ports of departure and entry. The measurement of interest for the record keeping would be the external dose rates outside the container, which houses the transportation cask since the port personnel do not enter the container. These measurements could be used to identify shipments that would result in port personnel exposures above those calculated based on the historical spent nuclear fuel transportation external dose rate. By tracking this information, DOE would be able to identify if and when additional precautions to reduce individual exposures should be taken.

D.4.6 Cumulative Port Impact Analysis Methodology

Analyses have been carried out to estimate the maximum occupational doses associated with the port activities segment of the transportation of foreign research reactor spent nuclear fuel. Since port workers are expected to be exposed to other shipments of radioactive materials, the cumulative impact of all radioactive material shipments has been estimated. The cumulative analysis is necessary to determine the impact on port workers from doses received through actions associated with the foreign research reactor spent fuel return program and through other actions, both DOE and commercially initiated.

The maximum exposure for a worker involved in transporting the foreign research reactor fuel is predicted to result from activities associated with the unloading of the spent fuel casks in port, cask inspection, and cask preparation for truck shipment to the management sites. If the same individuals were present for all proposed shipments of foreign research spent nuclear fuel on an annual basis (a conservative assumption), the maximum dose would be approximately 150 mrem, as discussed in the previous section. This estimate is based on the use of the "exclusive use" regulatory external dose rate. Based on historical spent nuclear fuel shipment data, this maximum annual dose would be 15 mrem.

Since commercial ports routinely receive other shipments of radioactive materials under other DOE programs or other commercial activities, the port worker would also be potentially exposed to additional sources of radiation. To estimate the annual exposure rate of port workers resulting from handling of commercial radioactive material shipments, the following must be determined.

- Number of radioactive packages handled per year
- Length of exposure time per package
- Dose rate per package

Records of shipments through the potential ports of entry were used to estimate the annual throughput of packages with radioactive contents. Radioactive materials were identified by the product code listed for each shipment. The radioactive shipments were then grouped into six categories and exposure rates at 1 m (3.3 ft) from the outer surface of the package were assigned for each group as follows:

• enriched uranium hexafluoride	(0.5 mrem per hour)
• normal uranium hexafluoride	(0.2 mrem per hour)
• depleted uranium	(0.2 mrem per hour)
• uranium oxide	(0.2 mrem per hour)
• spent nuclear fuel (foreign research reactor)	10 mrem per hour [at 2 m (6.6 ft) from the container surface]
• other radioactive materials	(0.2 mrem per hour)

Each shipment record lists the weight and number of packages included in the shipment. Since package descriptions were not uniform and included units, containers, cases, boxes, barrels, drums, packages, cartons, etc., the assumption was made that the radioactive shipments would be stacked on skids and the total number of skids per shipment, rather than the number of packages per shipment, would be used to estimate the dose received by workers. The weight and number of individual shipments was examined for each shipment to estimate the number of skids. In most cases, boxes, cartons, barrels, and drums were assumed to be handled four to a skid. When a large number of light packages was included in one shipment, these were assumed to be handled as either eight or 32 packages per skid.

The annual dose to port workers resulting from handling commercial radioactive shipments were estimated based on the number of shipments passing through the port and an estimated handling time of ten minutes per skid or cylinder. Each port typically uses three shifts per day and therefore workers were assumed to be exposed to one-third of the packages passing through the port. This is a conservative assumption given that there are typically many berths and terminals within one port, thus making it unlikely that one individual would be present for even one-third of the shipments of radioactive materials. The estimated dose to the MEI from these commercial shipments is shown in Table D-20.

Table D-20 Estimated Maximum Exposure to Dock Workers from Commercial Shipments of Radioactive Material

Port	*Average No. of Radioactive Shipments per Year*	*Estimated Maximum Exposure per Year (mrem)*	*Port*	*Average No. of Radioactive Shipments per Year*	*Estimated Maximum Exposure per Year (mrem)*
Baltimore, MD	31	3.4	New Orleans, LA	7	3.9
Boston, MA	2	0.2	Norfolk, VA	30	3.9
Charleston, SC	16	3.1	New York, NY	104	16.8
Fernandina Beach, FL	21	less than 0.1	Oakland, CA	39	9.0
Galveston, TX	1	less than 0.1	Philadelphia, PA	1	less than 0.1
Houston, TX	14	4.0	Portland, OR	1	0.6
Jacksonville, FL	4	0.3	Portsmouth, VA	28	5.5
Long Beach, CA	1	less than 0.1	Port Everglades, FL	7	0.1
Los Angeles, CA	6	0.2	Savannah, GA	7	1.5
Miami, FL	1	less than 0.1	Wilmington, NC	2	1.2

As this table shows, yearly exposures for the commercial shipments are typically less than 10 mrem per year, which is well within the regulatory limit of 100 mrem per year established for a member of the general public. New York (at 16.8 mrem per year), which had the most commercial shipments of radioactive material on a yearly basis, was the only port to exceed 10 mrem per year. However, the Port of New York consists of three terminals in Elizabeth (NJ), Brooklyn, and Manhattan. This diversity means that in practice, the average port worker would be involved in only a portion of the shipments through "New York."

Some of the potential ports are being used or have the potential to be used for other DOE-initiated activities. These activities include the purchase of Russian low enriched uranium (LEU) under the agreement Suspending the Antidumping Investigation of Uranium from the Russian Federation and the import of Russian LEU derived from the dismantling of nuclear weapons in Russia. Estimated maximum exposures from these activities are 0.9 mrem and 1.4 mrem per year, respectively.

The impact of all of these shipments can be viewed in two ways. If the foreign research reactor spent nuclear fuel shipments were to have dose rates like the historical data indicate they would, the total maximum worker exposure from all of these activities would be well below the public dose limits (by at least a factor of three). If the foreign research reactor spent nuclear fuel shipments were to be closer to the external dose rate allowed by the "exclusive use" regulatory limit, these other activities do not significantly alter the maximum worker dose. In this case, DOE's response to the worker exposure would be dictated by the exposure resulting from the shipment of foreign research reactor spent nuclear fuel.

D.4.7 Incident-Free Port Impacts of Alternatives to the Basic Implementation of Management Alternative 1

Three alternatives to the basic implementation of Management Alternative 1 were identified that could impact the incident-free port risk calculations that were performed. (Chapter 2 describes the alternatives to the basic implementation of Management Alternative 1.) The implementation subalternative of *accepting spent nuclear fuel only from developing countries*, which are identified as countries other than high-income economies, would result in a reduction in the amount of spent nuclear fuel transported by ship. Table C-12 listed the countries that are considered to be countries other than high-income economies and the number of foreign research reactor spent nuclear fuel shipments that would be required to transport their spent nuclear fuel to the United States. One hundred sixty-eight transportation casks would be shipped to the United States under this implementation subalternative. Under the *foreign research reactor spent nuclear fuel for 5-years only* implementation subalternative, the number of shipments of foreign research reactor spent nuclear fuel would be reduced to 586 shipments requiring ocean transport. (The derivation of the number of shipments required in this alternative is presented in Appendix B.)

The third alternative, with the capability to impact the results of the incident-free port risk analysis, is the *overseas processing of the foreign research reactor spent nuclear fuel with the shipment of the vitrified waste to a storage facility in the United States*. Under this alternative, eight transportation cask shipments of vitrified waste could be made.

In addition to these alternatives, a hybrid alternative was analyzed. In this alternative, those countries that have the capability to store high-level waste would be encouraged to process the aluminum-based research reactor spent nuclear fuel and to accept for storage the resulting high-level waste. (For this alternative these countries are assumed to be Belgium, France, Germany, Italy, Spain, Switzerland, and the United Kingdom). The United States would accept for storage the foreign research reactor spent nuclear fuel from those countries deemed not to have the high-level waste storage capability. In this alternative, this includes all of the countries identified in Table C-1, except for those listed above. Under this hybrid alternative, 452 shipments of foreign research reactor spent nuclear fuel are assumed to be sent to the United States, excluding overland shipments of Canadian origin.

The incident-free port risks associated with these three alternatives are discussed in the following sections.

Implementation Subalternative 1a of Management Alternative 1 – Acceptance of Foreign Research Reactor Spent Nuclear Fuel Only From Developing Countries: Developing countries are defined as countries other than high-income economies. As stated above, this implementation subalternative would result in the shipment of 168 transportation casks of foreign research reactor spent nuclear fuel. The assumptions used in the analysis of the basic implementation of Management Alternative 1 incident-free port impact have been used in the analysis of this subalternative. To compare this subalternative to the basic implementation of Management Alternative 1, it is only necessary to perform the analysis using one external dose rate, either the regulatory dose limit or the historic dose rate. The regulatory dose rate was chosen for the comparison.

Included in the assumptions that have not changed in this analysis are the following:

- The worker exposure times and distances from the transportation cask are as detailed in Tables D-8 through D-10.
- The intermediate port stops are considered for the breakbulk vessel but not for the container vessel.

- Two transportation casks are being transported in the same hold on each cargo vessel.

The per shipment incident-free impact on the port workers would be identical to that calculated for the basic implementation of Management Alternative 1. None of the assumptions used to generate the per shipment information change. The 168 shipments required to meet the needs of this subalternative would result in a reduction in the total (program) impacts by approximately 77 percent. The total population exposure would range from 7.0 person-rem (for the breakbulk vessel with two intermediate port calls) to 1.9 person-rem (for the container vessel with no intermediate port stops). This corresponds to an incident-free risk of 0.0028 to 0.00076 LCFs (i.e., a chance of between three-in-a-thousand and seven-in-ten thousand of incurring one LCF).

Implementation Subalternative 2a of Management Alternative 1 – Acceptance of Foreign Research Reactor Spent Nuclear Fuel for 5 Year Policy Duration: As stated above, this implementation subalternative would result in the shipment of 586 transportation casks of foreign research reactor spent nuclear fuel. The assumptions used previously for incident-free port impact have been used in the analysis of this subalternative. This implementation subalternative has been analyzed using the "exclusive use" regulatory limit transportation cask external dose rates. To compare this implementation subalternative to the basic implementation of Management Alternative 1, it is only necessary to perform the analysis using one external dose rate.

Included in the assumptions that have not changed in this analysis are the following:

- The worker exposure times and distances from the transportation cask are as detailed in Tables D-8 through D-10.

- The intermediate port stops are considered for the breakbulk vessel but not for the container vessel.

- Two transportation casks are being shipped in the same hold of each cargo vessel.

The per shipment incident-free impact on the port workers would be identical to that calculated for the basic implementation of Management Alternative 1. Therefore, none of the assumptions used to generate the per shipment information change. The 586 shipments required to meet the needs of this implementation subalternative would result in a reduction in the total (program) impacts to approximately 81 percent of the impacts associated with the basic implementation of Management Alternative 1. The total population exposure would be 25 person-rem (for the breakbulk vessel with two intermediate port calls) to 6.7 person-rem (for the container vessel with no intermediate port stops). This corresponds to an incident-free risk of 0.0098 to 0.0027 LCFs (i.e., a chance of between one-in-a-hundred and three-in-a-thousand of incurring one LCF).

Management Alternative 2, Subalternative 1b – Overseas Reprocessing with Shipment of the Vitrified Waste to a U.S. Storage Facility: In this subalternative under Management Alternative 2, the foreign research reactor spent nuclear fuel would be processed overseas (most probably in Great Britain or France) and the waste products are contained within several vitrified waste logs. This high-level waste may be brought to the United States for storage in one of the storage facilities evaluated under this EIS. Under these conditions, up to eight transportation casks containing vitrified waste would be shipped from Europe to the United States. This analysis addresses the incident-free port risks associated with transporting these eight casks of vitrified waste from Europe to the United States.

As with the shipment of foreign research reactor spent nuclear fuel as spent nuclear fuel, the primary incident-free port impacts of shipping vitrified waste would be upon the workers in the ports. The assumptions used in the analysis of the incident-free port impact of the basic implementation of Management Alternative 1 have been used in the analysis of this subalternative. Differences between the foreign research reactor spent nuclear fuel transportation casks and the vitrified waste transportation casks are not expected to significantly alter the work requirements in port. For the purposes of this analysis, it has been assumed that the vitrified waste would be transported on a chartered vessel, and there would be no intermediate port calls.

This alternative has been analyzed using the regulatory limit transportation cask external dose rates. Little information is available on the casks to be used to transport the vitrified waste. No attempt was made to extrapolate limited historical data to determine the port worker incident-free impacts from any other exposure rate other than the limit set forth in NRC and DOE regulations.

Included in the assumptions that have not changed in this analysis are the following:

- The worker exposure times and distances from the transportation cask are as detailed in Tables D-8 through D-10.
- The intermediate port stops are not considered for the container vessel.
- Two transportation casks are being transported in the same hold of the cargo vessels.

The per shipment incident-free impact on the port workers would be identical to that calculated for the basic implementation of Management Alternative 1. None of the assumptions used to generate the per shipment information change. The eight shipments required to meet the needs of this subalternative would result in a reduction in the total (program) impacts by a factor of approximately one hundred. The total population exposure would be 0.0091 person-rem for the container vessel with no intermediate port stops. This corresponds to an incident-free risk of 0.0000036 LCFs (i.e., a chance of approximately four-in-a-million of incurring one LCF).

Hybrid Alternative – Acceptance of Foreign Research Reactor Spent Nuclear Fuel From Countries Without High-Level Waste Disposal Capability: As stated above, this hybrid alternative results in the marine shipment of 452 transportation casks of foreign research reactor spent nuclear fuel. The assumptions used in the analysis of the incident-free port impact of the basic implementation of Management Alternative 1 have been used in the analysis of this alternative. This alternative has been analyzed using external dose rates derived from the exclusive use regulatory limit for a transportation cask.

Included in the assumptions that have not changed in this analysis are the following:

- The worker exposure times and distances from the transportation cask.
- The intermediate port stops are considered for the nonchartered vessel but not for the chartered vessel.
- Two transportation casks are being shipped in the same hold of each cargo vessel.

The per-shipment incident-free impact on the port workers would be identical to that calculated for the basic implementation of Management Alternative 1. None of the assumptions used to generate the per-shipment information changes. The 452 shipments required to meet the needs of this hybrid alternative would result in a reduction in the total (program) impacts to approximately 63 percent of the impacts associated with the basic implementation of Management Alternative 1. Therefore, the total population exposure would be 19 person-rem (for regularly scheduled commercial vessel with two intermediate port calls) to 5.1 person-rem (for the chartered vessel with no intermediate port calls). This corresponds to an incident-free risk of 0.0076 to 0.0021 LCFs (i.e., a chance of between approximately one-in-five hundred to less than one-in-a-hundred of incurring one LCF).

D.5 Accident Impacts: Methods and Results

D.5.1 Introduction

This section describes the approach used to assess the risks associated with in-port accidents that could result in a release of radioactive material from the transportation cask containing foreign research reactor spent nuclear fuel. The discussion addresses both the accident risk assessment methodology and the results of the analyses. The risk assessment results are presented in terms of a per-shipment accident risk and the total port-accident risks associated with various alternative under the proposed action.

Spent nuclear fuel shipments could occur via any of four types of vessels, container ships, roll-on/roll-off vessels, breakbulk vessels, and purpose-built (dedicated) vessels. In the incident-free analysis, only breakbulk vessels and container vessels were studied, since these two provide a bounding assessment of the risks associated with port activities. Under the assumptions used in the port accident analysis, the type of vessel used to transport the foreign research reactor spent nuclear fuel would not impact the result of the analysis.

All radiologically-related impacts are calculated in terms of committed dose and associated health effects in the exposed populations. The radiation dose calculated is the total effective dose equivalent, which is the sum of the effective dose equivalent (EDE) from the external radiation exposure and the 50 year committed effective dose equivalent from internal radiation exposure. Radiation doses are presented in units of person-rem for collective population and rem or mrem for individuals. The impacts are further expressed as health risks, specifically in terms of LCF. The health risk conversion factors were derived from International Commission on Radiological Protection Publication 60 (ICRP, 1991). See Chapter 4 for a more complete explanation of radiation measurement and health risks.

D.5.1.1 Accident Risks

Risk (R) is the product of the magnitude (M) of an unfavorable consequence and the probability of occurrence (P) of that consequence. Thus,

$$R = PM.$$

For accidents that happen during the transportation of radioactive materials, the unfavorable consequences of the accident may include exposure of people to radiation emitted by the radioactive materials released to the atmosphere by the accident and the occurrence of radiation induced health effects that the exposure may cause. The magnitude of these consequences depends on the amount of radioactivity released to the atmosphere, the degree to which the radioactive materials are diluted during downwind transport, and the size of the population that is exposed to radiation from the passing plume or from materials deposited on the ground or in the water from the plume. The amount of dilution experienced by a plume during downwind transport depends principally on atmospheric stability and windspeed. The size of the exposed population is determined by the direction the wind is blowing at the time of the accident and the number of people in that direction. Thus, the probability that a given consequence occurs is given by the following product,

$$P = P_{st} P_w P_p$$

where P_{st} is the probability of the source term (the amount of radioactive material released), P_W is the probability of the prevailing weather conditions, and P_p is the exposure probability of the population that is exposed to radiation, given the direction that the wind is blowing at the time of the accident.

D.5.1.2 Ship Accident Risks

The total risk caused by transporting foreign research reactor spent fuel to and within the United States is the sum of the risks for transport by land and by ship. Thus,

$$R_{total} = R_{land} + R_{ship}$$

For ships, the risk is given by:

$$R_{ship} = R_{sea} + R_{coast} + R_{port}$$

where R_{sea}, R_{coast}, and R_{port} are the risk while at sea, while sailing in coastal waters, and while in the port (R_{sea} and R_{coast} were addressed in Appendix C). Each risk term has an incident-free and an accident contribution, so

$$R_{port} = R_{port\text{-}incident\text{-}free} + R_{port\text{-}accident}$$

The accident risks associated with the foreign research reactor spent nuclear fuel while it is on a ship in the port, $R_{port\text{-}accident}$, is the subject of this section. $R_{port\text{-}incident\text{-}free}$ was covered in D.4 of this appendix.

The only port accidents considered are those where the ship carrying the spent nuclear fuel is struck by another ship. Accidents where the spent nuclear fuel transport ship rams a fixed structure (a bridge or a dock), rams another ship (a collision where the spent nuclear fuel ship is the striking ship), or runs aground are neglected for the following reasons.

First, ship accident data show that when a ship rams a fixed structure or collides with another ship, damage to the striking ship is confined to its prow and to the forwardmost hold. Even in these cases, the forces exerted on cargo in the forward hold are less than the forces exerted on cargo in the case where a striking ship impacts the cargo hold.

Second, because keel structures are massive and very sturdy, groundings rarely lead to significant damage to cargo, although monetary losses due to sinking of cargo or the ship can be significant. Immersion to the depths of harbor channels is unlikely to damage a spent nuclear fuel cask or pose a significant retrieval problem; therefore, groundings are also neglected in this study.

D.5.2 Risk Analysis Methods

The consequences of ship collisions that occur in ports were estimated using the MELCOR Accident Consequences Code System (MACCS) (Jow et al., 1990, Sprung et al., 1990), originally developed by Sandia National Laboratories and the NRC for use in estimating the consequences of nuclear power plant accidents. The MACCS code was selected for these analyses because it can model an accident that takes place at a specific location and, more importantly, can model the site-specific population distribution around that location including space that is ocean and thus unpopulated.

If a ship transporting spent nuclear fuel is struck by another ship, and the collision leads to the failure of the spent fuel cask, the prevailing winds would transport the radioactive gases and aerosols in the plume released to the atmosphere during the accident away from the accident scene. During transport by the prevailing winds, downwind populations would likely be exposed to radiation, and land, buildings, and crops located below the plume trajectory might be contaminated by the radioactive materials deposited from the plume. Estimation of the range and probability of the health effects induced by the radiation exposures, and of the economic costs and losses that would result from any contamination of land, buildings, and crops is the objective of a MACCS accident consequence analysis.

MACCS calculations require the following accident and site data:

The radioactive inventory of the cask at the time of the accident for those radionuclides important for the calculation of accident consequences.

Release fractions and probability of release for the source term caused by the accident.

Plume characteristics for the radioactivity released to the atmosphere by the accident, the sensible heat content and the release time and duration.

Meteorological data characteristic of the region where the port is located, usually one year of hourly readings of windspeed, atmospheric stability, and rainfall.

The population distribution about the port where the accident occurs.

Emergency response assumptions, such as evacuation time and average speed; building shielding factors and the time when people take shelter if nearby populations are instructed to take shelter.

Land usage (habitable land fractions and farmland fractions) for the region surrounding the port.

Given these data, MACCS predicts:

The downwind transport, dispersion, and deposition of the radioactive materials released from the failed spent fuel cask.

The radiation doses received by the exposed populations via direct (cloudshine, inhalation, groundshine, resuspension) and indirect (ingestion) exposure pathways.

The mitigation of these doses by emergency response actions (evacuation, sheltering, and post-accident relocation of people).

Health effects that might occur in the population exposed to radiation as a result of the accident, both LCF and acute injuries (if short-term exposures are large).

The potential costs of emergency response actions, and of the decontamination, temporary interdiction, and condemnation of milk, crops, land, and buildings located in the region around the port, if necessary.

D.5.3 MACCS Input Data

D.5.3.1 Source Terms

MACCS source terms are specified by five input quantities: the probability (P_{st}) of the accident that leads to the release; the time (t) and duration (delta t) of the release (for ship accidents there may be both a mechanical release following the collision and a later thermal release if the accident progression leads to a fire); and the accident release fraction (f_i) and cask inventory (I_i) of each radionuclide (i) important for the calculation of accident consequences.

D.5.3.1.1 Source Term Probabilities

In the Environmental Assessment for the Urgent Relief Acceptance of Foreign Research Reactor Spent Nuclear Fuel (DOE, 1994d), accident risks were estimated using six categories of accident severity. To facilitate comparison of the risk estimates developed for this EIS to those developed for the Environmental Assessment, the EIS retained these six categories of accidents. Table D-21 presents the six categories of accident severity used in the EIS (and Environmental Assessment), the values of the conditional release probabilities (conditional on the occurrence of the specified accident), and the radionuclide release fractions used in the EIS for each severity category.

Inspection of the table shows that no radioactive releases are expected for accidents that fall into severity categories 1 or 2. Accidents that fall into category 3 fail the cask's seal but not the fuel elements contained within the cask. Thus, only radioactivity produced by activation of chemical deposits located on the outside of the fuel elements corrosion deposits can be released. Since research reactor fuel is not significantly plagued by corrosion deposit formation, corrosion deposits are negligible for research reactor spent fuel. Although the accident phenomenology specified for category 6 is more severe than that for category 5, and that for category 5 is more severe than that for category 4, in the Environmental Assessment all three of these categories were assigned a conditional probability of occurrence of 0.0004. Since increasing accident severity should mean decreasing accident probability, the conditional probabilities assigned to these categories should not be identical. Although the Environmental Assessment release fractions given in the table were retained as the base case for analysis, a method to develop new estimates of the conditional probabilities of occurrence for categories 4, 5, and 6 was formulated. That method is presented below.

D.5.3.1.2 EIS Source Term Probability Considerations

Table D-22 presents a sequence of events that encompasses the accident conditions associated with accident severity categories 4, 5, and 6. This sequence of events provides a reasonable description of a severe collision between large ships that leads both to a severe fire and to a release of radioactivity from the violated spent fuel cask.

This construct allows source term probabilities (P_{st}) to be estimated as the product of the probabilities of occurrence for the seven events. Table D-23 shows how values for P_{st} were calculated in this analysis for accident severity categories 4 through 6. $P_{collision}$ and $P_{severe\ fire}$ were estimated from ship accident data. Because data were sparse for some of the ports studied, these probabilities were not developed separately for each port (i.e., dependencies on port traffic were neglected). P_{hold} and $P_{engulfing\ fire}$ were derived from ship specifications (number of cargo holds and the dimensions of these holds for the prototypic breakbulk freighter used in the impact and crush analyses). P_{impact} and P_{crush} were estimated, as is described in

Table D-21 Accident Severity Categories Used in the EIS

Accident Severity Category	Accident Conditions	Conditional Probabilities	Radionuclide Release Fractions[a]
1	Conditions do not exceed those for a Type B package; no release of contents.	0.603	Co 0 Kr 0 Cs 0 Ru 0 Part 0
2	Conditions equal to those for Type B certification tests; no release of contents.	0.395	Co 0 Kr 0 Cs 0 Ru 0 Particulate 0
3	Seal damage creates leak path, but fuel undamaged; only corrosion deposits, if present, released from package.	0.002	Co 0.012 Kr 0 Cs 0 Ru 0 Particulate 0
4	Impact damage great enough to cause damage to spent fuel; fuel particulates and fission gases may be released.	0.0004	Co 0.012 Kr 0.010 Cs 0.00000001 Ru 0.00000001 Particulate 0.00000001
5	Impact damage to seals plus fire severe enough to cause the cask to leak with release of fission gases, volatiles, and particulates.	0.0004	Co 0.012 Kr 0.100 Cs 0.0009 Ru 0.000001 Particulate 0.00000005
6	Severe impact damage plus fire severe enough to oxidize fuel with release of greater amounts of volatiles than Category 5.	0.0004	Co 0.012 Kr 0.100 Cs 0.00098 Ru 0.000042 Particulate 0.00000005

[a] *No credit was taken for the deposition of fission product vapors or aerosols released from a failed cask onto surfaces of the ship or cargo.*

Table D-22 Event Sequence for a Severe Ship Accident

Event	Event Probability
Collision between large ships	$P_{collision}$
Foreign research reactor spent nuclear fuel hold struck	P_{hold}
Foreign research reactor spent nuclear fuel hold penetrated (the cask and fuel are subjected to impact forces)	P_{impact}
Cargo compression (the cask is subjected to crush forces)	P_{crush}
Severe fire ensues	$P_{severe\ fire}$
Fire engulfs the cask (heat loads are sufficient to vaporize cesium)	$P_{engulfing\ fire}$
Convective flow of air through cask causes ruthenium to oxidize	$P_{convection}$

Attachment D4, using the methods of Minorsky (Minorsky, 1959) and results from previous studies of ship accidents (ORI, 1981b). $P_{convection}$ was estimated by review of data on fires and on the temperatures required to oxidize ruthenium to RuO_4, which is necessary to yield the higher ruthenium release fractions.

Table D-23 EIS Source Term Probability Expressions

Accident Severity Category	*Probability*
4	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})$
5	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}$
6	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}P_{convection}$

D.5.3.1.3 Probabilities Developed From Accident Data

Fifteen years of Lloyd's casualty data (Lloyds, 1991) and previous studies of ship accidents (Warwick, 1976; SRI, 1978; ORI, 1981a; Abkowitz, 1985) were reviewed to develop (1) the probability of a severe collision ($P_{collision}$) between large ships that occurs dockside in ports or while sailing in port channels, and (2) the probability that such a collision leads to a severe fire (P_{fire}).

Collision Probability

Ship accident casualty data for the years 1978 through 1993 and U.S. port call data for the years 1992 and 1993 were obtained from Lloyd's Maritime Information Services, Inc. Searches of the port call data for the 2-year period 1992-1993 identified the number of port calls made in U.S. ports by all ships, all dry cargo ships, and all dry cargo ships of deadweight 10 to 20 thousand long tons (equivalent to approximately 10,160 to 20,321 metric tons or 11,200 to 22,400 tons). The searches were performed twice, once restricting the results to collision that occurred in port waters only and once adding collisions that occurred in restricted approaches (rivers) that lead to the port. The addition of restricted approach waters was done to permit comparison to results from the literature that included or seemed to include collisions in the river that leads to a port.

The collision frequency per port call is based on a relatively small numbers of collisions. The 15 years of Lloyd's data contained only 69 collisions that occurred in U.S. ports or the restricted river waters that lead to them. Because of this, it is inappropriate to select a value for $P_{collision}$ that is significantly more precise than an order-of-magnitude estimate. The Lloyd's data indicate that for all types of commercial vessels in all U.S. ports, the number of collisions per port call is 0.000077. Other studies provide a range of values for collisions per port call (Warwick, 1976; SRI, 1978; ORI, 1981a; Abkowitz, 1985); however, the Lloyd's database is the most inclusive and the largest (based on approximately 900,000 port calls), so the result based on their data was used here. As discussed earlier, only an order-of-magnitude value is warranted, so the 0.000077 collision per port call was rounded up to 0.0001 ($P_{collision} = 0.0001$).

Probability of Severe Fires

The sources of information cited above were examined to determine an estimate of the probability of a severe fire, given a ship collision. Four estimates of this probability were developed. The 15 years of Lloyd's casualty data contains 1,073 ship collisions in ports located anywhere in the world. Eleven of these collisions led to fires, five caused extensive fire damage, and one involved buckling of structures due to thermal loads. Therefore, the Lloyd's data suggest that the chance that a ship collision leads to a severe fire is 5/1073 = 0.0045.

Only one of the 83 collisions identified by Warwick and Anderson (Warwick, 1976) led to a fire. However, that fire consumed one of the ships involved, the *Sea Witch*. Thus, the Warwick and Anderson data suggest that the chance that a collision will lead to a severe fire is 1/83 = 0.012.

Only 17 of the 391 collisions in the Abkowitz and Galarraga study (Abkowitz, 1985) led to fires of any severity. Thus, the probability that a collision leads to a fire of any severity is 17/391 = 0.044. SRI data suggest that about five percent of all ship fires involve an entire hold (SRI, 1978). Thus, the chance that a ship fire on a cargo ship will involve an entire hold is about 0.05. Combining these last two results allows the probability that a cargo ship collision leads to a severe fire to be estimated as follows:

(fires per collision) x (fires involving an entire hold per fire) =

$$(4.4x10^{-2})\ x\ (0.05) = 0.0022 \text{ severe fires per collision}$$

Fires on cargo ships were reviewed by several countries for the International Maritime Organization. The French submission (IMO, 1992) to the International Maritime Organization developed data for 599 cargo ship fires that took place during the 11-year period 1978-1988. Only 2 of the 599 fires were caused by ship collisions. Thus, the probability that a collision leads to a fire of any severity is 2/599 = 0.017. Of the 599 fires, 122 led to immediate total loss, and 195 led to damage first thought to be repairable but which later was determined to be beyond repair. Thus, the chance that a fire is severe is greater than 122/599 = 0.20 and less than (122+195)/599 = 0.53. If the average of these two estimates is used, then the probability that a collision leads to a severe fire can again be calculated as was just done above:

(fires per collision) x (fires resulting in total loss per fire) =

$$(1.7x10^{-2})\ x\ (0.37) = 0.0063 \text{ severe fires per collision}$$

If these four estimates for severe fires per collision are averaged, a value of 0.0063 results. Rounding to the nearest order-of-magnitude suggests that $P_{severe\ fire}$ = 0.01 is a reasonable estimate for the chance that a severe fire will be caused by a ship collision.

No credit is taken for fighting of hold fires during accidents that occur in U.S. ports, all of which have fire fighting equipment, even though fighting of hold fires with water should keep fire temperatures well below those assumed in this study.

D.5.3.1.4 Probability of Mechanical Loads That Cause Damage

A severe ship collision could damage a spent nuclear fuel transportation cask and the elements contained in the cask by subjecting the cask to impact forces, crush forces, and/or thermal loads. Because force is the derivative of energy with distance, both impact forces and crush forces at any penetration distance (d) can be estimated by differentiating expressions that give the dependence on distance of the kinetic energy that is dissipated during the collision. Attachment D4 provides the details of this analysis. In Section 1 of Attachment D4, the kinetic energy associated with ship collisions is discussed. Next, in Section 2, the impact forces required to damage a cask and/or the fuel elements inside the cask are estimated. The crush forces required to damage a cask or the fuel elements inside the cask are described in Section 3.

The kinetic energy associated with ship collisions has been studied (Minorsky, 1959) and extended to develop correlations between penetration depth and energy absorbed. The methodology addresses the evaluation of the kinetic energy, impact forces, and crush forces and their relationship to the impact and crush probabilities (P_{impact} and P_{crush}) associated with ship collisions. The results of this evaluation concluded that P_{crush} is equal to 0.40, and P_{impact} is equal to 0.0.

D.5.3.1.5 Probabilities Developed From Ship Design Data

Two probabilities can be derived from the general ship design data, P_{hold} and $P_{engulfing\ fire}$. The first of these probabilities addresses the likelihood that the collision results in damage to the hold in which the spent nuclear fuel cask resides. (If the cask is stowed in an aft hold and the collision results in damage to a forward hold, no cask damage would be expected.) The second probability addresses the likelihood that the severe fire resulting from the accident (see Section D.5.3.1.3) is located in the same hold and on the same deck as the cask of spent nuclear fuel.

If foreign research reactor spent fuel casks were shipped one at a time, as is assumed here, then P_{hold}, the probability that the hold that contains the cask is the hold that is struck, can be approximated by $1/N_{hold}$, where N_{hold} is the number of holds in the ship transporting the spent nuclear fuel cask. The representative breakbulk freighter used in the impact and crush analyses described below has seven holds. Therefore, for this prototypic ship, $P_{hold} = 1/7 = 0.143$.

The total cargo area of this typical breakbulk freighter is about 3,066 m^2 (33,000 ft^2). Each hold includes two, three, or four decks. Together, the seven holds encompass 21 decks. Thus, the area of each deck is about 3,066/21 = 146 m^2 (33,000/21 = 1,600 ft^2). The Pegase cask used as a prototype in this study has a 2.1-m by 3-m (7-ft by 10-ft) base. This cask should be completely engulfed by a pool fire that has a diameter of 9.1 m (30 ft), provided that the fire occurs in the same hold and on the same deck that the cask is stored on. Since a pool fire of diameter 9.1 m (30 ft) occupies about 65 m^2 (700 ft^2), any engulfing fire will probably involve an entire deck in a hold. If a collision can lead to a fire on any deck in the hold, the $P_{engulfing\ fire} = 1/21$. Limiting the location of the fire to the struck hold or an adjacent hold reduces the number of decks on which the fire could occur. In this case, the number of holds of interest is approximately ten, and therefore, $P_{engulfing\ fire} = 1/10$. Using the larger estimate gives $P_{engulfing\ fire} = 0.1$.

D.5.3.1.6 Probability of Convective Flow Through the Failed Cask

Nonuniform heating of the cask during engulfing fires is expected to produce substantial flow of gases through the cask if two or more small holes or one medium hole have been produced in the cask by the ship collision. Because transportation cask bottoms and lid seats are welded to the cylindrical shell of the cask using full-penetration welds that are as strong or stronger than the parent material, when the cask shell is subjected to a severe stress (e.g., high impact or crush forces), the cask shell should yield before the welds fail. In fact, extra-regulatory 97 km/hr (60 mph) drop tests produced large plastic strains in the cylindrical shell of the test cask without failing its welds (Ludwigsen and Ammerman, 1995). Thus, during a ship collision, crush forces should collapse the cask walls inward without producing catastrophic failure of the lid, its seat, or the welds that attach the seat or the bottom of the cask to the cask walls. Therefore, an unusual configuration of cargo and/or deformed ship structures must be produced during the ship collision in order to subject the cask to forces that will produce failures substantially worse than failure of the lid seal. Either the lid seat must be bent significantly, or at least two penetrations must break, or the cask walls must be sheared or punctured. Although data for such failures is lacking, because cask designs normally do not fail by these mechanisms, the probability that a failure substantially worse than seal failure occurs is conservatively assumed to be no larger than 0.1, therefore $P_{convection} = 0.1$.

D.5.3.1.7 Source Term Probability Values

Table D-24 summarizes the estimates developed for the probabilities that enter the EIS source term probability expressions presented in Table D-23.

Table D-24 Estimated Values for Probabilities in Source Term Probability Expressions

Severity Category	*Probability*	*Estimated Value*[a]
	$P_{collision}$	0.0001
	P_{hold}	0.143
	P_{impact}	0.0
	P_{crush}	0.40
	$P_{severe\ fire}$	0.01
	$P_{engulfing\ fire}$	0.1
	$P_{convection}$	0.1
4	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})$	0.000006
5	$P_{ST} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}$	5×10^{-9}
6	$P_{ST} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}\ P_{convection}$	6×10^{-10}

[a]*Severity category 6 is a subset of severity category 5, which in turn is a subset of severity category 4. Therefore, the final estimated value for each P was adjusted to account for this.*

D.5.3.1.8 Source Term Magnitudes

In MACCS, source term magnitudes (M_{sti}) are given by the product of the inventory (I_i) of radionuclides (i) available for release and the fraction (f_i) of that inventory that is released during the accident being examined. Therefore,

$$M_{sti} = I_i f_i.$$

Cask radionuclide inventories were developed for three types of research reactor fuel — Training, Research, Isotope, General Atomic (TRIGA), RHF, and BR2 — for use in the port accident analysis (see Appendix B). Table D-25 presents these inventories. Because it is partly metallic, the TRIGA fuel may undergo exothermic oxidation if exposed to air while at elevated temperatures during an accident involving an enveloping fire.

Because of the large number of casks that might be used to transport foreign research reactor spent nuclear fuel, analyses could not be performed for all possible cask/inventory combinations. Since the size of the cask, rather than the details of its construction, determines the size of the cask's inventory, construction details were obtained for one typical spent nuclear fuel transportation cask, and these construction data were the basis for analyses that depended on cask properties. See Appendix B for description and figures of transportation casks.

For base case analyses, the values for the release fractions (f_i) for the five representative elements, cobalt, krypton, cesium, ruthenium, and other (particulate), presented in Table D-21, were taken to be the same as the values presented that were used in the Environmental Assessment of Urgent Relief Acceptance of Foreign Research Reactor Spent Nuclear Fuel (DOE, 1994d). During the sensitivity studies described below, MACCS calculations were performed that used release fraction values and an inventory for foreign research reactor spent nuclear fuel that were taken from the DOE Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement (Programmatic SNF&INEL Final EIS) (DOE, 1995). Although both the Environmental Assessment and the Programmatic SNF&INEL Final EIS contain release fractions for all six of the severity categories used in the Environmental Assessment, calculations were not performed for the first two categories, because cask failure does not occur for either category, and only a limited number of sensitivity calculations were performed for category 3 because only

Table D-25 Curie Content of Fully Loaded Transportation Casks for Three Representative Fuel Types

Nuclide	Fuel		
	BR-2	RHF	TRIGA
Hydrogen-3	8.6	37	13
Krypton-85	2,470	1,070	363
Strontium-89	40,800	17,600	275
Strontium-Yttrium-90	20,800	8,930	3,160
Yttrium-91	73,000	31,400	4,560
Zirconium-95	107,000	46,300	6,480
Niobium-95	220,000	94,900	12,800
Ruthenium-103, Rh-103m	8,900	3,770	844
Ruthenium-106, Rh-106m	21,500	9,160	2,540
Tin-123	427	184	27
Antimony-125	890	381	119
Tellurium-125m	212	91	29
Tellurium-127m	887	382	56
Tellurium-129m	189	80	23
Cesium-134	16,400	4,000	1,160
Cesium-137	20,600	8,870	3,190
Cerium-141	5,740	2,440	697
Cerium-144	312,000	135,000	25,500
Promethium-147	48,300	24,600	7,020
Promethium-148m	75	29	47
Europium-154	620	163	42
Europium-155	130	46	23
Uranium-234	0.0009	0.0004	0.0001
Uranium-235	0.014	0.01	0.008
Uranium-238	0.0003	0.0002	0.007
Plutonium-238	64	10	3
Plutonium-239	1.8	0.09	0.6
Plutonium-240	1.2	0.4	2
Plutonium-241	284	68	213
Americium-241	0.4	0.1	0.4
Americium-242m	0.001	0.0001	0.009
Americium-243	0.004	0.004	0.0004
Curium-244	1.3	0.009	0.007
Curium-242	1.8	0.1	3

corrosion product are released in a category 3 accident, and only minor amounts of corrosion product deposits form on research reactor spent nuclear fuel. To examine the possible impacts of corrosion products release, during the sensitivity studies, one category 3 accident calculation was performed during which 350 Ci of Co-60 was the only nuclide released, and one calculation was performed that added the same amount of Co-60 to the base case calculation.

D.5.3.1.9 Source Term Timing and Sensible Heat

Ship accident source terms may have both a puff (an immediate release of most material) and a tail (a gradual release of the material over an extended time), where the puff follows the mechanical failure of the cask due to the collision forces, and the tail is produced by the slow heating of the cask contents by an ensuing fire. Because ship collisions are short duration events, if the collision causes a mechanical release, it should be of relatively short duration and the gases released from the cask should be cold (no significant sensible heat content) and thus not subject to plume rise. Conversely, because a substantial engulfing fire that burns for approximately an hour is required to heat both the cask and the spent nuclear fuel elements in the cask to temperatures where cesium compounds (for example, CsOH) vaporize to a significant extent, thermal releases will be delayed (release won't occur until about one hour after the collision) and will not take place rapidly (release duration of about one hour). Of course, if cask failure is caused by thermal rather than mechanical loads, any radioactivity released inside of the cask by the collision will not be released from the cask until the cask fails due to those thermal loads. Moreover, if heat loads cause the fuel elements in the cask to fail at essentially the same time that the cask seals fail due to thermal stress, a delayed short duration release could occur. Thus, ship accident source terms can have four release patterns: (1) a single short (15 minute) release caused by the mechanical forces engendered by the collision; (2) a single short (15 minute) release caused by the mechanical forces engendered by the collision followed by a longer (60 minute) release caused by the thermal loads produced by an ensuing fire; (3) a single long duration (60 minute) release caused by thermal loads on the cask if the collision does not lead to failure but an ensuing fire does; and (4) a single delayed short (15 minute) duration release if cask failure and burst rupture of fuel elements occur together.

Because a substantial engulfing fire of significant duration is required to cause a thermal release, for such thermal releases the radioactivity released from the failed cask will be assumed to be released into the fire plume, which typically will have a bulk gas temperature of about 1,200°K (1,700°F). Therefore, the sensible heat content of that plume will be 100 kilowatts for severity category 5 releases and 150 kilowatts for severity category 6 releases.

The start time and duration of the four release patterns described above are presented in Table D-26. For base case calculations, the first release pattern will be assumed for severity Category 4 accidents and the second pattern for severity Category 5 and 6 accidents. The third and forth release patterns will be examined by sensitivity studies.

Table D-26 Release Timing Patterns

Pattern	*Puff*		*Tail*	
	Release Start (min)	*Release Duration (min)*	*Release Start (min)*	*Release Duration (min)*
1	0	10		
2	0	10	60	60
3			60	60
4			90	10

D.5.3.2 Population Distributions

MACCS calculations require as input a population distribution and site-specific weather conditions. The populations along each of the sixteen compass sectors (N, NNE, NE, etc.) are used to determine the exposed population for each combination of site weather and wind rose conditions. Depending upon the shape of the plume, the exposed population includes the people along one or more adjacent sectors.

The required population distributions were generated for two locations at each of thirteen ports. Table D-27 lists the ports selected for examination in this study.

Table D-27 Ports Analyzed

Coast	High Population	Medium Population	Low Population
East	Philadelphia, PA New York, NY	Hampton Roads, VA Jacksonville, FL	Charleston, SC MOTSU, NC Savannah, GA Wilmington, NC
West	Long Beach, CA	Concord NWS, CA Portland, OR Tacoma, WA	
Gulf			Galveston, TX

Two accident locations were considered for each port, one at dockside and one channel location near the population center where a major ship collision would be possible. Two exceptions were made for ports able to share the same channel accident location due to their close proximity to each other. These exceptions are the Port of Wilmington and MOTSU, NC, as well as the Wando Terminal and the Charleston NWS in greater Charleston, SC. Population distributions were constructed on a compass-sector polar coordinate grid that has eleven radial interval (1.6, 3.2, 4.8, 6.4, 8.0, 16, 32, 48, 64, and 20 km or 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 mi). The distributions were constructed from 1990 block census data using Sandia's SECPOP90 code (Humphreys et al., 1994). The coordinates of the midpoint of the compass-sector polar coordinate grid were selected by inspection of navigational maps for the ports examined. Table D-28 gives the coordinates of these dockside and channel locations, which represent the selected locations for possible accidents. The population distributions generated by SECPOP90 represent the population in an 80.5 km (50 mi) radius around each potential accident site.

The 26 population distributions constructed (two per port) using SECPOP90 were entered into the site data file for the dockside or channel accident location at each of the thirteen ports. Examination of these files shows that many of the cells in the 26 population distributions are empty because they are covered by water (ocean, rivers, bays, harbor channels).

At many ports, the work force population is probably much larger than the residential population, at least in the commercial area near to the port. Therefore, the work force population was estimated for one port, Elizabeth, and added to the distribution that has been constructed for that port using SECPOP90. Then, during the sensitivity studies, the effect of the work force population on consequences of accidents at Elizabeth was examined.

D.5.3.3 Meteorological Data

MACCS calculations examine all possible combinations of a representative set of weather sequences and a representative set of population distributions. MACCS calculations require a site wind rose, to give the exposure probability of the compass sector population distributions and one year of hourly readings of wind speed, atmospheric stability, and rainfall rate. These data may be recorded either at the accident site or at some not-too-distant meteorological station that has similar meteorology and topography as the accident site. These data are used to determine dispersion as a function of downwind transport distance. Site wind rose and rainfall data were available for each of the ports studied. One year of hourly meteorological data was available from National Weather Service Stations located in the port city for only two of the 13 ports studied. For the other 11 ports, hourly meteorological data recorded at a nearby National Weather Service station was used during the base case calculations. Table D-29 presents the locations of the National Weather Service Stations where the hourly meteorological data files used in this study were recorded, and indicates the ports with which each file was used.

Table D-28 Accident Location Map Coordinates

Port	Location	Description	Coordinates	
			Latitude	Longitude
Elizabeth, NJ (for New York)	Dock	Marine Terminal, Sealand Pier	40°39'35"N	74°08'52"W
	Channel	Narrows	40° 36'29"N	74° 02'21"W
Philadelphia, PA	Dock	Packer Avenue Marine Terminal(container berths)	39° 53'55"N	75° 08'09"W
	Channel	Commodore Berry Fixed Bridge	39° 49'43"N	75° 22'18"W
Norfolk, VA (for Hampton Roads)	Dock	Portsmouth Marine Terminal	36° 51'25"N	76° 19'45"W
	Channel	Willoughby Bank, Northside	36° 59'57"N	76° 18'43"W
MOTSU, NC	Dock	Sunny Point, Wharf 1	33° 59'39"N	77° 51'21"W
	Channel	Lower Swash Channel	33° 54'39"N	78° 01'12"W
Charleston, SC	Dock	Pier at Wando Terminal	32° 49'51"N	79° 53'34"W
	Dock	Naval Weapons Station	32°56'12"N	79°56'11"W
	Channel	Commercial anchorage area D	32° 47'05"N	79° 55'10"W
Savannah, GA	Dock	Savannah Ocean Terminal	32° 05'00"N	81° 05'18"W
	Channel	Intersection Savannah River and Intracoastal Waterway at Elba Island Cut	32° 04'26"N	80° 58'17"W
Galveston, TX	Dock	Container Terminal, Pier 9	29° 19'00"N	94° 46'53"W
	Channel	Cross of Bolivar Roads Channel and Galveston Channel	29° 20'27"N	95° 46'12"W
Concord NWS, CA	Dock	Naval Weapons Station	38° 03'32"N	122° 00'49"W
	Channel	San Francisco Bay Temporary Anchorage No. 7 Shipping Lane Route	37°49'24"N	122°23'47"W
Tacoma, WA	Dock	Port of Tacoma Pier No. 7	47° 16'03"N	122°24'49"W
	Channel	Intersection of 4 shipping lanes in Puget Sound north of Port Townsend	48° 11'24"N	122°49'48"W
Wilmington, NC	Dock	Main Dock Wilmington Terminal	34° 13'03"N	77°57'09"W
	Channel	Lower Swash Channel	33° 54'39"N	78° 01'12"W
Jacksonville, FL	Dock	Blount Island Terminal	30° 23'16"N	81° 33'00"W
	Channel	St. John's River Ferry crossing to Mayport	30° 23'40"N	81° 26'00"W
Long Beach, CA	Dock	Pier E	33° 45'43"N	118° 12'31"W
	Channel	Breakwater East Side	33° 43'23"N	118° 10'53"W
Portland, OR	Dock	Terminal 2	45° 32'54"N	122° 41'56"W
	Channel	St. Johns Bridge	45° 35'04"N	122° 45'58"W

Table D-29 Locations of National Weather Service Stations

Port	National Weather Service Station
Elizabeth, NJ	New York City, NY
Philadelphia, PA	New York City, NY
Norfolk, VA	Cape Hatteras, NC
MOTSU, NC; Wilmington, NC	Cape Hatteras, NC
Charleston, SC; Savannah, GA; Jacksonville, FL	Charleston, SC
Long Beach, CA; Concord NWS, CA	Santa Maria, CA
Portland, OR; Tacoma, WA	Seattle, WA
Galveston, TX	Lake Charles, LA

Although MACCS calculations can use constant meteorology, one year of hourly meteorological data is preferred because adverse results are often the result of meteorological sequences that involve changing meteorological conditions. MACCS uses an importance sampling method to find these less probable sequences that yield adverse results. The sampling method examines all of the 8,760 weather sequences in one year of hourly data and selects the start times of the approximately 100 weather sequences that are used during a variable meteorology calculation. The impact of using constant versus variable meteorology is the subject of one of the sensitivity calculations.

D.5.4 MACCS Calculations

All of the MACCS calculations performed during this study used a source term probability of one. Thus, the consequence estimates generated and the probabilities associated with those estimates are conditional on the release of the source term (i.e., the estimates are conditional on the accident having occurred).

For any source term, a MACCS calculation generates results for all possible combinations of a representative set of weather sequences and a representative set of exposed downwind populations. Since the probability of occurrence of each weather sequence and the exposure probability of each population distribution is known, the variability of consequences due to weather and population conditional on the accident having occurred can be displayed by plotting the probability that a consequence magnitude will be equaled or exceeded against consequence magnitude. Such a plot is called a Complementary Cumulative Distribution Function.

Two types of MACCS accident consequence calculations were performed, base case calculations and sensitivity calculations. Base case calculations used:

- the inventories given in Table D-25,
- the release fractions presented in Table D-21 for severity categories 4, 5, and 6,
- the release timings specified in Table D-26 (pattern 1 was used for severity category 4 releases and pattern 3 for category 5 and 6 releases),
- one year of hourly meteorological data recorded at the National Weather Service Station listed in Table D-29, and
- population distributions calculated using SECPOP90 for the dockside and channel locations presented in Table D-28.

Population distributions and other site-specific data are input to MACCS via a site data file.

Sensitivity calculations modified the input used in the base case calculations to identify the influence on consequences:

- of using variable meteorology recorded offsite at a nearby National Weather Service station rather than constant meteorology recorded onsite at the harbor,
- of using source terms that contained 17 nuclides for which acute health effect dose conversion factors were not available,
- of neglecting the enhanced shielding likely to be afforded to population near to the harbor by the masonry buildings that typify construction in urban commercial neighborhoods,

- of using release fractions developed for the Programmatic SNF&INEL Final EIS (DOE, 1995) for truck and rail accidents,
- of adding the harbor work force population to the residential population distribution,
- of modeling extremely high temperature effects on aluminum-based and TRIGA fuels release fractions,
- of modeling accidents that lead to severe fires using a puff and a tail (two segment release) rather than only a puff, and
- of adding cobalt-60 to the inventory so that corrosion products release can be calculated.

The results of these sensitivity calculations are presented in Section D.5.4.3.

Both the variable meteorology and the constant meteorology MACCS calculations performed for this study consist of a large number of individual trials (about 1,750 trials for each variable meteorology calculation; about 1,150 trials for each constant meteorology calculation). By accumulating the results of the individual trials, an expected (mean) result and a Complementary Cumulative Distribution Function are generated for each output quantity (result) calculated. In addition, for each output calculated, the value of the largest result obtained for any individual trial, the probability of occurrence of that trial, and the weather sequence used in that trial are saved by MACCS.

D.5.4.1 Acute Health Effects

The MACCS code can calculate the numbers of fatalities and injuries that are caused by acute exposures that occur over time periods of a few days (due to dose to the stomach or the intestines) to one year (due to internal dose to the lungs). Of the seven acute injuries that MACCS can examine, prodromal vomiting is the acute injury most likely to appear at low doses and dose rates. Because the occurrence of acute health effects would be cause for considerable concern, acute fatalities and cases of prodromal vomiting were calculated during every MACCS run made during this study; and the output of every run was inspected to see if either acute effect had occurred. Inspection of all of the MACCS output generated showed that no acute fatalities and no cases of prodromal vomiting were ever predicted to occur for any output quantile (i.e., the mean result, all quantile values on the Complementary Cumulative Distribution Function, and the result obtained for the least favorable weather sequence were all zero for acute fatalities and cases of prodromal vomiting).

D.5.4.2 Base Case Calculations

The base case calculations estimated the consequences that might result if any one of nine ship accidents (the combination of three cask inventories presented in Table D-25, with the release fractions for accident severity categories 4, 5, and 6) occurred at any of the 25 accident locations examined (one dockside and one channel location at each of the 13 ports, except MOTSU and Wilmington, which share a channel accident location). Thus, 3 x 3 x 25 = 225 base case MACCS calculations were performed and are presented in this assessment.

D.5.4.2.1 Typical Output

Table D-30 presents MACCS output for one base case calculation, the calculation for the channel accident location at Elizabeth performed with the BR-2 source term and severity categories 4, 5, and 6 release fractions. Using as an example the severity category 5 results, the first group of results in this table are

Table D-30 Sample Output from MACCS

SITE=NEW LOC=CHANNEL INV=BR-2 ST=EA4 VAR MET=NYC

		PROB			QUANTILES				PEAK	PEAK	PEAK
		NON-ZERO	MEAN	50TH	90TH	95TH	99TH	99.9TH	CONS	PROB	TRIAL
EARLY + CHRONIC RESULTS											
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1.6 KM	0.5675	4.16E-05	2.43E-07	1.30E-04	2.15E-04	4.38E-04	8.02E-04	1.13E-03	2.50E-04	73
CAN FAT/TOTAL	0-80.5 KM	1.0000	1.64E-04	7.15E-05	4.38E-04	6.29E-04	9.89E-04	1.29E-03	1.50E-03	2.50E-04	73
POPULATION DOSE (SV)											
EDEWBODY TOT LIF	0-1.6 KM	0.5675	9.45E-04	5.56E-06	2.90E-03	4.96E-03	1.03E-02	1.56E-02	2.56E-02	2.50E-04	73
EDEWBODY TOT LIF	0-8.1 KM	0.8016	2.42E-03	1.01E-03	7.02E-03	9.14E-03	1.60E-02	2.50E-02	3.30E-02	2.50E-04	73
EDEWBODY TOT LIF	0-16.1 KM	0.8848	3.04E-03	1.18E-03	8.37E-03	1.16E-02	2.04E-02	2.59E-02	3.37E-02	2.50E-04	73
EDEWBODY TOT LIF	0-80.5 KM	1.0000	3.76E-03	1.65E-03	9.67E-03	1.33E-02	2.27E-02	3.13E-02	3.41E-02	2.50E-04	73
CENTERLINE DOSE AT SOME DISTANCES (SV)											
EDEWBODY TOT LIF	0-1.6 KM	1.0000	5.98E-07	4.09E-07	1.13E-06	1.48E-06	2.39E-06	NOT-FOUND	3.66E-06	3.45E-03	73
CHRONIC RESULTS ONLY											
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1.6 KM	0.5675	3.50E-05	2.28E-07	1.11E-04	1.86E-04	3.60E-04	6.54E-04	9.36E-04	2.50E-04	73
CAN FAT/TOTAL	0-80.5 KM	1.0000	1.40E-04	6.32E-05	3.67E-04	5.20E-04	8.26E-04	1.11E-03	1.24E-03	2.50E-04	73
EDEWBODY POP. DOSE (SV)	0-80.5 KM										
TOTAL LONG-TERM PATHWAYS DOSE		1.0000	3.35E-03	1.46E-03	9.03E-03	1.21E-02	2.05E-02	2.58E-02	2.96E-02	2.50E-04	73
TOTAL INGESTION PATHWAYS DOSE		1.0000	5.65E-05	4.28E-05	1.18E-04	1.60E-04	2.50E-04	3.14E-04	3.57E-04	2.24E-05	28
LONG-TERM GROUNDSHINE DOSE		1.0000	2.66E-03	1.15E-03	6.82E-03	9.90E-03	1.43E-02	2.13E-02	2.39E-02	2.50E-04	73
ECONOMIC COST MEASURES ($)	0-80.5 KM										
TOTAL ECONOMIC COSTS		0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0
CROP DISPOSAL COST		0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0
MAXIMUM LONG-TERM ACTION DISTANCE (KM)											
CROP DISPOSAL DIST.		0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0

SITE=NEW LOC=CHANNEL INV=BR-2 ST=EA5 VAR MET=NYC

		PROB			QUANTILES				PEAK	PEAK	PEAK
		NON-ZERO	MEAN	50TH	90TH	95TH	99TH	99.9TH	CONS	PROB	TRIAL
EARLY + CHRONIC RESULTS											
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1.6 KM	0.6818	9.85E-02	2.32E-06	2.71E-02	2.60E-01	2.60E+00	6.86E+00	1.75E+01	7.65E-05	45
CAN FAT/TOTAL	0-80.5 KM	1.0000	2.90E+00	1.22E+00	7.38E+00	1.17E+01	2.91E+01	3.89E+01	5.53E+01	7.65E-05	45
POPULATION DOSE (SV)											
EDEWBODY TOT LIF	0-1.6 KM	0.6818	2.36E+00	5.22E-05	6.05E-01	6.11E+00	6.21E+01	1.74E+02	4.21E+02	7.65E-05	45
EDEWBODY TOT LIF	0-8.1 KM	0.8854	1.57E+01	2.08E-01	3.35E+01	6.23E+01	3.23E+02	5.13E+02	9.27E+02	9.81E-05	45
EDEWBODY TOT LIF	0-16.1 KM	0.9686	3.30E+01	3.13E+00	9.40E+01	1.48E+02	5.48E+02	8.50E+02	1.25E+03	1.16E-05	44
EDEWBODY TOT LIF	0-80.5 KM	1.0000	6.93E+01	2.84E+01	1.80E+02	2.61E+02	7.09E+02	9.41E+02	1.33E+03	7.65E-05	45
CENTERLINE DOSE AT SOME DISTANCES (SV)											
EDEWBODY TOT LIF	0-1.6 KM	1.0000	1.17E-03	1.60E-06	5.29E-03	6.69E-03	1.52E-02	NOT-FOUND	4.12E-02	1.06E-03	45
CHRONIC RESULTS ONLY											
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1.6 KM	0.6371	9.83E-02	2.14E-07	2.71E-02	2.60E-01	2.60E+00	6.86E+00	1.75E+01	7.65E-05	45
CAN FAT/TOTAL	0-80.5 KM	0.9943	2.90E+00	1.22E+00	7.38E+00	1.17E+01	2.88E+01	3.89E+01	5.53E+01	7.65E-05	45
EDEWBODY POP. DOSE (SV)	0-80.5 KM										
TOTAL LONG-TERM PATHWAYS DOSE		0.9943	6.92E+01	2.84E+01	1.80E+02	2.61E+02	7.09E+02	9.41E+02	1.33E+03	7.65E-05	45
TOTAL INGESTION PATHWAYS DOSE		0.9943	1.70E+00	2.50E-01	6.02E+00	8.37E+00	1.07E+01	1.24E+01	1.66E+01	9.94E-06	25
LONG-TERM GROUNDSHINE DOSE		0.9942	6.72E+01	2.61E+01	1.77E+02	2.57E+02	7.09E+02	9.41E+02	1.32E+03	7.65E-05	45
ECONOMIC COST MEASURES ($)	0-80.5 KM										
TOTAL ECONOMIC COSTS		0.0038	1.80E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NOT-FOUND	5.64E+03	2.44E-03	16
CROP DISPOSAL COST		0.0038	1.33E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NOT-FOUND	4.15E+03	2.44E-03	16
MAXIMUM LONG-TERM ACTION DISTANCE (KM)											
CROP DISPOSAL DIST.		0.0038	6.12E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NOT-FOUND	1.61E+00	3.80E-03	16

SITE=NEW LOC=CHANNEL INV=BR-2 ST=EA6 VAR MET=NYC

		PROB			QUANTILES				PEAK	PEAK	PEAK
		NON-ZERO	MEAN	50TH	90TH	95TH	99TH	99.9TH	CONS	PROB	TRIAL
EARLY + CHRONIC RESULTS											
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1.6 KM	0.6713	8.02E-02	7.79E-07	1.48E-02	1.73E-01	2.59E+00	7.25E+00	1.91E+01	7.65E-05	45
CAN FAT/TOTAL	0-80.5 KM	1.0000	2.84E+00	1.14E+00	6.92E+00	1.14E+01	3.15E+01	4.36E+01	6.04E+01	7.65E-05	45
POPULATION DOSE (SV)											
EDEWBODY TOT LIF	0-1.6 KM	0.6713	1.92E+00	1.98E-05	3.56E-01	3.03E+00	6.20E+01	1.88E+02	4.59E+02	7.65E-05	45
EDEWBODY TOT LIF	0-8.1 KM	0.8854	1.43E+01	2.64E-02	2.23E+01	4.25E+01	3.31E+02	5.41E+02	1.01E+03	7.65E-05	45
EDEWBODY TOT LIF	0-16.1 KM	0.9686	3.02E+01	5.66E-01	7.75E+01	1.32E+02	5.82E+02	8.62E+02	1.37E+03	1.16E-05	44
EDEWBODY TOT LIF	0-80.5 KM	1.0000	6.77E+01	2.71E+01	1.61E+02	2.57E+02	7.46E+02	1.08E+03	1.45E+03	7.65E-05	45
CENTERLINE DOSE AT SOME DISTANCES (SV)											
EDEWBODY TOT LIF	0-1.6 KM	1.0000	9.53E-04	3.45E-07	1.32E-03	6.25E-03	1.75E-02	NOT-FOUND	4.50E-02	1.06E-03	45
CHRONIC RESULTS ONLY											
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1.6 KM	0.5752	8.01E-02	0.00E+00	1.48E-02	1.73E-01	2.59E+00	7.25E+00	1.91E+01	7.65E-05	45
CAN FAT/TOTAL	0-80.5 KM	0.9879	2.83E+00	1.14E+00	6.92E+00	1.13E+01	3.15E+01	4.36E+01	6.04E+01	7.65E-05	45
EDEWBODY POP. DOSE (SV)	0-80.5 KM										
TOTAL LONG-TERM PATHWAYS DOSE		0.9879	6.76E+01	2.71E+01	1.61E+02	2.57E+02	7.46E+02	1.08E+03	1.45E+03	7.65E-05	45
TOTAL INGESTION PATHWAYS DOSE		0.9879	1.83E+00	2.61E-01	6.23E+00	8.54E+00	1.09E+01	1.29E+01	1.81E+01	9.94E-06	25
LONG-TERM GROUNDSHINE DOSE		0.9879	6.54E+01	2.46E+01	1.59E+02	2.55E+02	7.42E+02	1.06E+03	1.44E+03	7.65E-05	45
ECONOMIC COST MEASURES ($)	0-80.5 KM										
TOTAL ECONOMIC COSTS		0.0038	1.80E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NOT-FOUND	5.64E+03	2.44E-03	16
CROP DISPOSAL COST		0.0038	1.33E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NOT-FOUND	4.15E+03	2.44E-03	16
MAXIMUM LONG-TERM ACTION DISTANCE (KM)											
CROP DISPOSAL DIST.		0.0038	6.12E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NOT-FOUND	1.61E+00	3.80E-03	16

Health Effect Cases. The first health effect considered is the number of cancer fatalities expected to occur among the population located within 1.6 km (1 mi) of the accident location. For this population group, the table shows:

- that the probability of getting a nonzero result is 0.6818 which means that not even a fractional cancer fatality was predicted to occur in this population group for 31.82 percent of the approximately 1,750 trials run during this calculation (conversely, at least a fractional cancer death was predicted to occur in 68.18 percent of the trials);
- that the expected (mean) number of cancer fatalities for this population group is 0.098;
- that the 90th and 99th quantiles of the Complementary Cumulative Distribution Function of cancer fatalities for this population group have values of 0.0271 and 2.60; and
- that the largest number of cancer fatalities predicted for this population group for any weather trial was 17.5, that this result had a probability of occurrence of 0.000077, and that the 45th weather sequence selected by the importance sampling scheme led to this result. While the number of LCF is two orders of magnitude higher than the mean, the probability of occurrence of this peak value is four orders of magnitude lower than the mean value.

Figure D-54 presents the Complementary Cumulative Distribution Function for cancer fatalities among the population located within 1.6 km (1 mi) of the channel accident location at Elizabeth, for a severity category 5 accident release fraction. Figure D-54 shows that there is one chance in a thousand (probability = 0.001) that an accident that leads to a severity category 5 release from a cask that contains the BR-2 inventory will produce at least seven cancer deaths. Thus, the 99.9th quantile of the Complementary Cumulative Distribution Function has a value of about seven. Inspection of the Complementary Cumulative Distribution Function also shows that the tail of the distribution has a probability of occurrence of 0.0001 and a magnitude of about 17. These are the values produced by the weather trial that led to the largest result among the full set of weather trials.

The results presented in Table D-30 illustrate a pattern that is general over all of the calculations performed: population dose increases monotonically as distance range increases (e.g., 0-1.6 km, 0-8.1 km, ..., 0-80.5 km). Although not shown in Table D-30, this applies to cancer deaths also. Note that all doses are in Sieverts.

The centerline dose to an individual standing under the plume decreases monotonically with increasing distance, as it should, until it reaches the last computational interval (64.4-80.5 km or 40-50 mi, not shown on D-30) where counter-intuitively it increases. It increases because, during all calculations, rain was artificially forced to occur when the radioactive plume entered this computational interval in order to ensure that all radioactive particulates in the plume deposit onto the ground before the plume exits the computational grid at 80.5 km (50 mi) from the accident location. Deposition of all remaining radioactive particulates onto the ground within the last computational interval ensures that all radioactivity that might enter food pathways at some time after the accident does enter those pathways.

Another pattern that can be seen from Table D-30 is that total population dose is caused almost entirely by long-term groundshine exposures (external direct exposure to radiation emitted by radionuclides deposited on the ground).

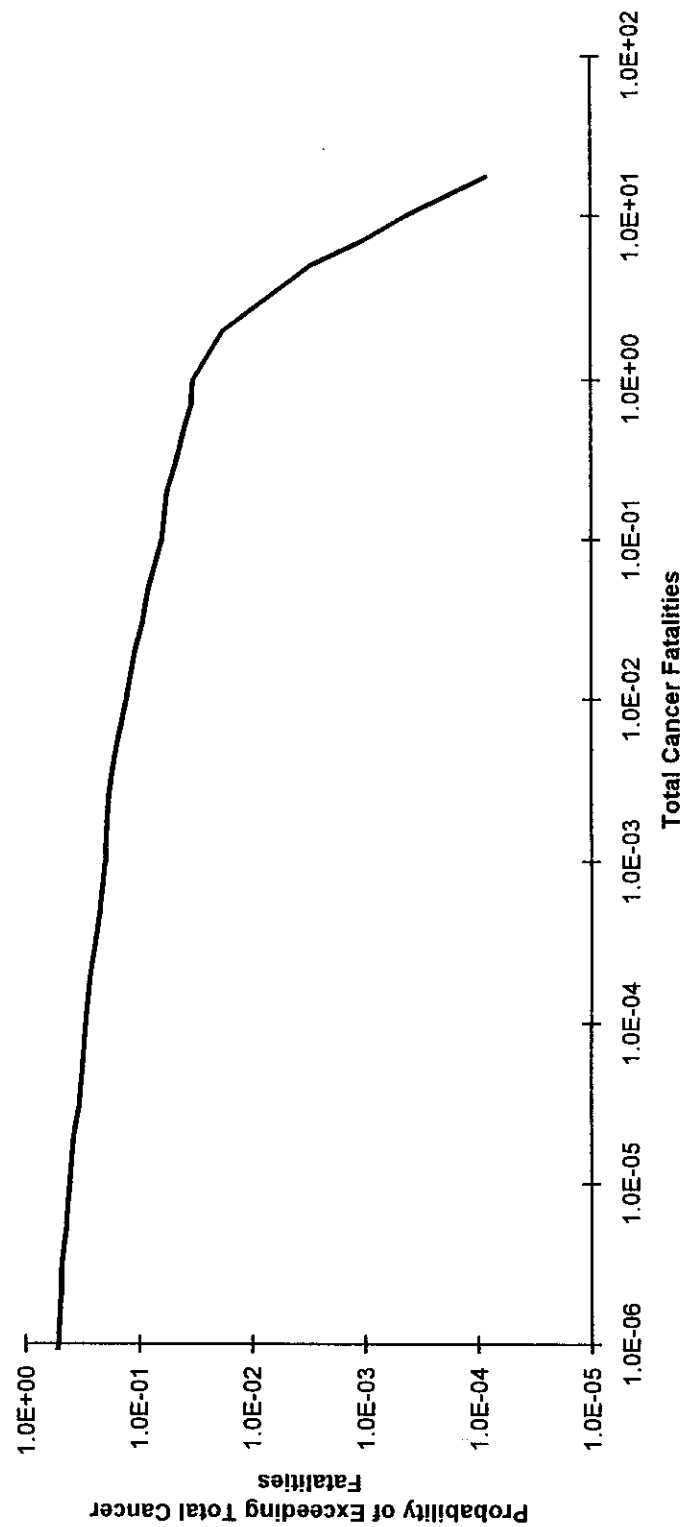

Figure D-54 Total Cancer Fatalities, 0-1.6 km (0-1 mi), Elizabeth Channel, Variable Meteorology, BR-2 Inventory, Severity Category 5

D-30 also shows that the economic losses (costs) caused by the accident are very small (expected value of \$18.00; peak value of \$5,640) and are entirely attributable to the disposal of contaminated crops and milk by farms located close to the accident site (the largest disposal distance found was 1.6 km or 1 mi). This also is typical of the MACCS output for all accidents analyzed.

The values of mean (expected) centerline dose (D_{cl}) (not shown in Table D-30) for severity category 5 release fractions are plotted versus distance (d) in Figure D-55. The figure shows that on a log-log plot dose decreases linearly with distance with a slope very close to minus one. Therefore, as one would expect, individual centerline dose is inversely proportional to distance ($D_{Cl} \propto {}^{1}/_{d}$).

Table D-30 presents a breakdown of long-term population dose (calculated as a wholebody dose by the Effective Dose Equivalent method and thus labeled EDEWBODY POP. DOSE) by exposure pathways. Inspection of this breakdown and comparison of the total long-term pathway dose to the total population dose for release category 5, mean results, in the 0-80.5 km (0-50 mi) ranges shows:

- that the total population dose 6,930 rem (69.3 Sv), is almost entirely due to the 6,920 rem (69.2 Sv) dose delivered by long-term exposure pathways;
- that short-term (acute) pathways deliver only a minor dose of 10 rem (0.1 Sv), which is the difference between the 69.3 Sv and the 69.2 Sv;
- that the long-term dose of 6,920 rem (69.2 Sv) is caused mainly by direct exposure pathways [6,750 rem (67.5 Sv)] and only secondarily by ingestion pathways [170 rem (1.7 Sv)];
- that groundshine [6,720 rem (67.2 Sv)] causes almost all of the long-term direct dose; resuspension (external direct exposure to radiation emitted by radionuclides resuspended from the ground) causes the rest of the long-term pathway dose, 30 rem (0.3 Sv);
- that the dose from radioactivity deposited directly on food crops [125 rem (1.25 Sv)] or on grass consumed by milk cows [30 rem (0.30 Sv)] accounts for most ingestion dose; and
- that the rest of the ingestion dose is caused by root uptake [to food crops, 10 rem (0.10 Sv); to grass and fodder crops, 4 rem (0.04 Sv)] with drinking of contaminated water causing only a very small dose of 1 rem (0.01 Sv).

D.5.4.2.2 Principal Base Case Consequence Results

Accident consequence mean (expected) values for whole body population dose and total cancer fatalities for the distance range 0-80.5 km (0-50 mi), and individual centerline dose and individual centerline cancer risk for the distance range 0-1.6 km (0-1 mi) are presented in Table D-31. Table D-32 provides 99.9th quantile values for whole body population dose and total cancer fatalities for the range 0-80.5 km (0-50 mi). Table D-33 presents the largest (peak) result calculated for individual centerline dose and cancer risk in the range 0-1.6 km or 0-1 mi. Table D-34 presents probabilities of the largest results calculated.

Table D-31 shows that the expected total population dose within 80.5 km (50 mi) of the accident location varies from a low of 0.000972 person-rem (0.00000972 person-Sv) for the MOTSU dock calculation that used the TRIGA inventory, severity category 4 (EA4) release fractions, and Cape Hatteras weather to a high of 6,930 person-rem (69.3 person-Sv) for the Elizabeth channel calculation that used the BR-2 inventory, severity category 5 (EA5) release fractions, and New York City weather. Since the total

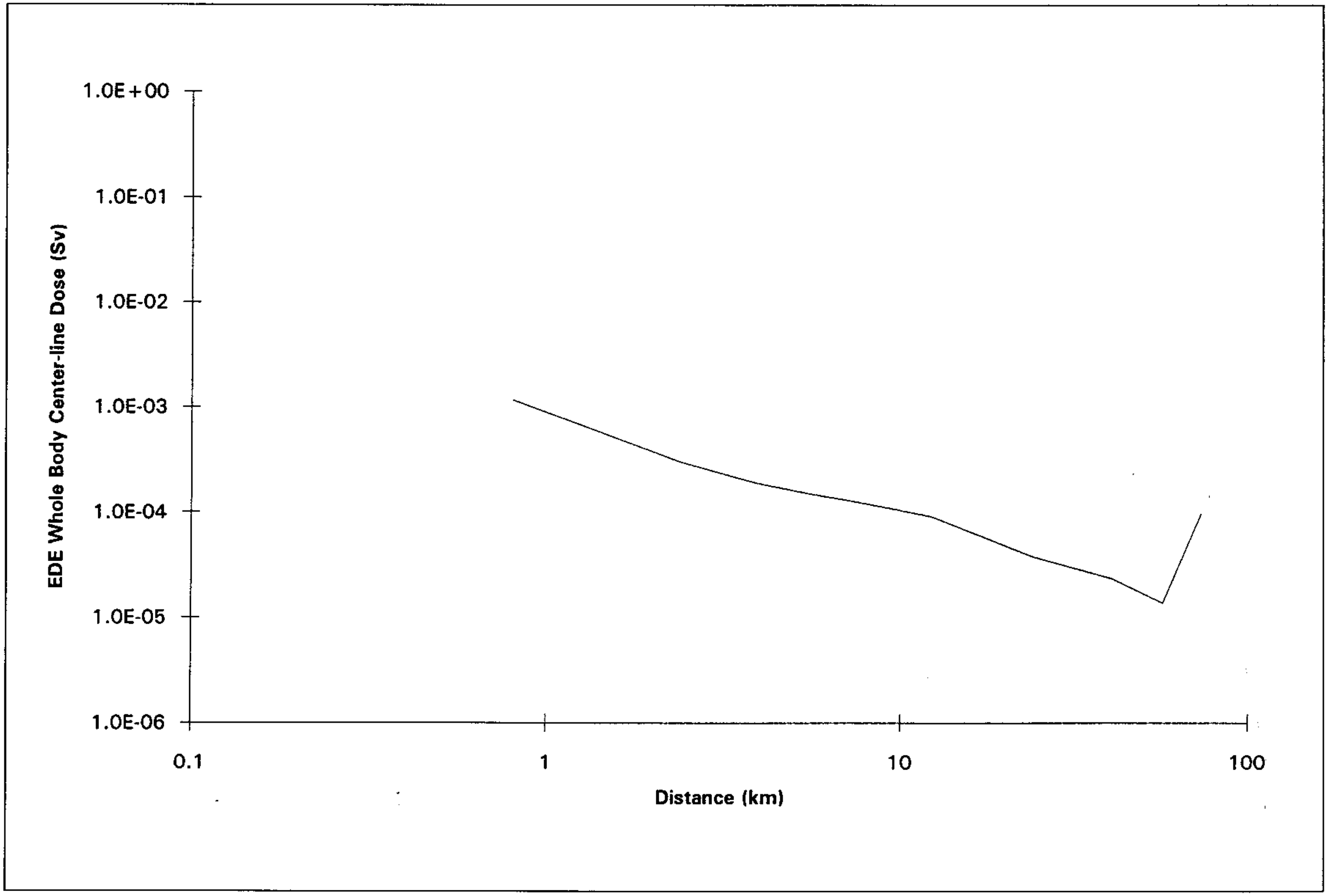

Figure D-55 Mean Effective Dose Equivalent Whole Body Center-Line Dose (Sv) vs Distance, Elizabeth Channel, Variable Meteorology, BR-2 Inventory, Severity Category 5

Table D-31 Mean Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	2.40E-04	4.15E+00	4.13E+00	9.55E-05	1.54E+00	1.53E+00	2.97E-05	5.32E-01	5.26E-01
CHA-C	3.78E-04	4.18E+00	4.21E+00	1.51E-04	1.55E+00	1.56E+00	4.58E-05	5.35E-01	5.37E-01
CNC-D	4.40E-04	2.07E+01	2.21E+01	1.76E-04	7.97E+00	8.51E+00	5.43E-05	2.78E+00	2.97E+00
CNC-C	9.44E-04	3.31E+01	3.40E+01	3.77E-04	1.29E+01	1.32E+01	1.13E-04	4.52E+00	4.63E+00
GAL-D	7.26E-04	1.44E+01	1.58E+01	2.90E-04	5.45E+00	6.00E+00	8.94E-05	1.90E+00	2.08E+00
GAL-C	3.23E-04	1.42E+01	1.55E+01	1.29E-04	5.36E+00	5.89E+00	4.13E-05	1.86E+00	2.04E+00
JAC-D	2.79E-04	6.82E+00	6.76E+00	1.11E-04	2.55E+00	2.52E+00	3.48E-05	8.84E-01	8.71E-01
JAC-C	2.58E-04	5.33E+00	5.45E+00	1.03E-04	1.99E+00	2.03E+00	3.22E-05	6.87E-01	6.99E-01
LOS-D	2.13E-03	4.71E+01	4.82E+01	8.52E-04	1.85E+01	1.89E+01	2.54E-04	6.49E+00	6.62E+00
LOS-C	8.09E-04	4.26E+01	4.40E+01	3.23E-04	1.67E+01	1.73E+01	9.72E-05	5.86E+00	6.05E+00
MOT-D	7.24E-05	2.08E+00	2.21E+00	2.88E-05	7.45E-01	7.91E-01	9.72E-06	2.54E-01	2.70E-01
NEW-D	2.33E-03	6.55E+01	6.51E+01	9.30E-04	2.58E+01	2.56E+01	2.77E-04	9.07E+00	9.00E+00
NEW-C	3.76E-03	6.93E+01	6.77E+01	1.50E-03	2.73E+01	2.67E+01	4.46E-04	9.60E+00	9.37E+00
NOR-D	5.52E-04	8.54E+00	8.32E+00	2.20E-04	3.25E+00	3.15E+00	6.69E-05	1.13E+00	1.09E+00
NOR-C	3.02E-04	6.65E+00	6.64E+00	1.21E-04	2.51E+00	2.50E+00	3.70E-05	8.73E-01	8.67E-01
PHI-D	1.77E-03	2.81E+01	2.78E+01	7.08E-04	1.10E+01	1.08E+01	2.11E-04	3.84E+00	3.79E+00
PHI-C	8.48E-04	2.74E+01	2.81E+01	3.39E-04	1.07E+01	1.09E+01	1.02E-04	3.74E+00	3.83E+00
POR-D	7.70E-04	1.17E+01	1.19E+01	3.07E-04	4.45E+00	4.50E+00	9.32E-05	1.55E+00	1.56E+00
POR-C	5.33E-04	1.12E+01	1.15E+01	2.13E-04	4.26E+00	4.36E+00	6.52E-05	1.48E+00	1.51E+00
SAV-D	5.60E-04	4.91E+00	5.01E+00	2.23E-04	1.80E+00	1.83E+00	6.82E-05	6.18E-01	6.28E-01
SAV-C	1.34E-04	3.82E+00	3.93E+00	5.32E-05	1.38E+00	1.42E+00	1.75E-05	4.74E-01	4.86E-01
SEA-C	1.31E-04	7.54E+00	8.29E+00	5.21E-05	2.84E+00	3.12E+00	1.68E-05	9.86E-01	1.08E+00
TAC-D	5.55E-04	1.73E+01	1.83E+01	2.21E-04	6.67E+00	7.02E+00	6.81E-05	2.33E+00	2.45E+00
TAC-C	3.87E-04	1.43E+01	1.50E+01	1.55E-04	5.50E+00	5.73E+00	4.75E-05	1.92E+00	2.00E+00
WIL-D	3.80E-04	4.82E+00	5.02E+00	1.51E-04	1.79E+00	1.86E+00	4.66E-05	6.19E-01	6.43E-01
WIL-C	9.65E-05	2.07E+00	2.20E+00	3.84E-05	7.47E-01	7.96E-01	1.24E-05	2.56E-01	2.72E-01
CHN-D	1.67E-04	4.76E+00	4.74E+00	6.63E-05	1.76E+00	1.77E+00	2.13E-05	6.09E-01	6.08E-01

Total Cancer Fatalities, 0-80 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.05E-05	1.89E-01	1.90E-01	4.20E-06	6.97E-02	6.95E-02	1.24E-06	2.40E-02	2.39E-02
CHA-C	1.66E-05	1.90E-01	1.93E-01	6.65E-06	7.01E-02	7.08E-02	1.90E-06	2.41E-02	2.43E-02
CNC-D	1.91E-05	8.96E-01	9.57E-01	7.63E-06	3.44E-01	3.67E-01	2.23E-06	1.20E-01	1.28E-01
CNC-C	4.10E-05	1.41E+00	1.45E+00	1.65E-05	5.48E-01	5.62E-01	4.63E-06	1.92E-01	1.97E-01
GAL-D	3.17E-05	6.39E-01	7.02E-01	1.27E-05	2.41E-01	2.65E-01	3.70E-06	8.35E-02	9.17E-02
GAL-C	1.39E-05	6.30E-01	6.92E-01	5.57E-06	2.37E-01	2.60E-01	1.71E-06	8.20E-02	9.01E-02
JAC-D	1.22E-05	3.07E-01	3.06E-01	4.88E-06	1.14E-01	1.13E-01	1.45E-06	3.94E-02	3.91E-02
JAC-C	1.13E-05	2.42E-01	2.49E-01	4.51E-06	8.95E-02	9.16E-02	1.34E-06	3.09E-02	3.15E-02
LOS-D	9.32E-05	1.99E+00	2.04E+00	3.75E-05	7.79E-01	7.97E-01	1.04E-05	2.73E-01	2.79E-01
LOS-C	3.51E-05	1.80E+00	1.86E+00	1.41E-05	7.05E-01	7.28E-01	3.96E-06	2.47E-01	2.55E-01
MOT-D	3.16E-06	9.94E-02	1.06E-01	1.25E-06	3.53E-02	3.76E-02	4.13E-07	1.20E-02	1.28E-02
NEW-D	1.02E-04	2.75E+00	2.73E+00	4.09E-05	1.08E+00	1.07E+00	1.13E-05	3.80E-01	3.77E-01
NEW-C	1.64E-04	2.90E+00	2.84E+00	6.62E-05	1.14E+00	1.12E+00	1.83E-05	4.01E-01	3.92E-01
NOR-D	2.42E-05	3.77E-01	3.70E-01	9.71E-06	1.42E-01	1.39E-01	2.76E-06	4.94E-02	4.82E-02
NOR-C	1.32E-05	2.96E-01	2.97E-01	5.30E-06	1.11E-01	1.11E-01	1.53E-06	3.85E-02	3.84E-02
PHI-D	7.75E-05	1.20E+00	1.19E+00	3.12E-05	4.66E-01	4.61E-01	8.67E-06	1.63E-01	1.61E-01
PHI-C	3.70E-05	1.17E+00	1.20E+00	1.49E-05	4.53E-01	4.66E-01	4.19E-06	1.59E-01	1.63E-01
POR-D	3.37E-05	5.18E-01	5.27E-01	1.35E-05	1.95E-01	1.98E-01	3.85E-06	6.78E-02	6.87E-02
POR-C	2.33E-05	4.97E-01	5.12E-01	9.34E-06	1.87E-01	1.92E-01	2.70E-06	6.50E-02	6.66E-02
SAV-D	2.46E-05	2.28E-01	2.34E-01	9.87E-06	8.28E-02	8.46E-02	2.83E-06	2.84E-02	2.90E-02
SAV-C	5.88E-06	1.79E-01	1.85E-01	2.32E-06	6.45E-02	6.65E-02	7.42E-07	2.20E-02	2.27E-02
SEA-C	5.61E-06	3.37E-01	3.70E-01	2.23E-06	1.26E-01	1.39E-01	6.93E-07	4.36E-02	4.79E-02
TAC-D	2.41E-05	7.54E-01	7.95E-01	9.66E-06	2.88E-01	3.04E-01	2.81E-06	1.00E-01	1.06E-01
TAC-C	1.68E-05	6.26E-01	6.55E-01	6.75E-06	2.38E-01	2.49E-01	1.95E-06	8.30E-02	8.66E-02
WIL-D	1.66E-05	2.19E-01	2.29E-01	6.66E-06	8.09E-02	8.43E-02	1.93E-06	2.79E-02	2.90E-02
WIL-C	4.22E-06	9.76E-02	1.04E-01	1.68E-06	3.50E-02	3.74E-02	5.22E-07	1.20E-02	1.28E-02
CHN-D	6.76E-06	2.17E-01	2.19E-01	2.67E-06	7.98E-02	8.03E-02	8.44E-07	2.75E-02	2.76E-02

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-31 Mean Results, Variable Meteorology (Continued)

Individual Center-line EDE Whole Body Dose, 0-1.6 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
CHA-C	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
CNC-D	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
CNC-C	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
GAL-D	9.29E-07	6.52E-04	6.91E-04	3.71E-07	2.58E-04	2.74E-04	1.05E-07	9.08E-05	9.62E-05
GAL-C	9.29E-07	6.52E-04	6.91E-04	3.71E-07	2.58E-04	2.74E-04	1.05E-07	9.08E-05	9.62E-05
JAC-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
JAC-C	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
LOS-D	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
LOS-C	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
MOT-D	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
NEW-D	5.98E-07	1.17E-03	9.53E-04	2.39E-07	4.63E-04	3.77E-04	6.81E-08	1.63E-04	1.33E-04
NEW-C	5.98E-07	1.17E-03	9.53E-04	2.39E-07	4.63E-04	3.77E-04	6.81E-08	1.63E-04	1.33E-04
NOR-D	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
NOR-C	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
PHI-D	1.01E-06	6.31E-04	6.59E-04	4.02E-07	2.50E-04	2.61E-04	1.14E-07	8.78E-05	9.16E-05
PHI-C	1.01E-06	6.31E-04	6.59E-04	4.02E-07	2.50E-04	2.61E-04	1.14E-07	8.78E-05	9.16E-05
POR-D	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
POR-C	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
SAV-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
SAV-C	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
SEA-C	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
TAC-D	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
TAC-C	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
WIL-D	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
WIL-C	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
CHN-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05

Individual Center-line Cancer Risk, 0-1.6 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
CHA-C	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
CNC-D	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
CNC-C	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
GAL-D	4.43E-08	2.72E-05	2.88E-05	1.80E-08	1.08E-05	1.14E-05	4.63E-09	3.78E-06	4.01E-06
GAL-C	4.43E-08	2.72E-05	2.88E-05	1.80E-08	1.08E-05	1.14E-05	4.63E-09	3.78E-06	4.01E-06
JAC-D	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
JAC-C	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
LOS-D	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
LOS-C	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
MOT-D	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
NEW-D	2.80E-08	4.88E-05	3.97E-05	1.14E-08	1.93E-05	1.57E-05	2.96E-09	6.78E-06	5.52E-06
NEW-C	2.80E-08	4.88E-05	3.97E-05	1.14E-08	1.93E-05	1.57E-05	2.96E-09	6.78E-06	5.52E-06
NOR-D	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
NOR-C	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
PHI-D	4.80E-08	2.63E-05	2.75E-05	1.95E-08	1.04E-05	1.09E-05	5.01E-09	3.66E-06	3.82E-06
PHI-C	4.80E-08	2.63E-05	2.75E-05	1.95E-08	1.04E-05	1.09E-05	5.01E-09	3.66E-06	3.82E-06
POR-D	3.55E-08	3.15E-05	3.32E-05	1.44E-08	1.25E-05	1.31E-05	3.74E-09	4.38E-06	4.62E-06
POR-C	3.55E-08	3.15E-05	3.32E-05	1.44E-08	1.25E-05	1.31E-05	3.74E-09	4.38E-06	4.62E-06
SAV-D	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
SAV-C	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
SEA-C	3.55E-08	3.15E-05	3.32E-05	1.44E-08	1.25E-05	1.31E-05	3.74E-09	4.38E-06	4.62E-06
TAC-D	3.55E-08	3.15E-05	3.32E-05	1.44E-08	1.25E-05	1.31E-05	3.74E-09	4.38E-06	4.62E-06
TAC-C	3.55E-08	3.15E-05	3.32E-05	1.44E-08	1.25E-05	1.31E-05	3.74E-09	4.38E-06	4.62E-06
WIL-D	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
WIL-C	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
CHN-D	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-32 99.9th Quantile Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

		BR-2			RHF			TRIGA	
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.20E-03	4.63E+01	5.26E+01	3.82E-04	1.71E+01	2.04E+01	1.30E-04	6.21E+00	7.13E+00
CHA-C	3.40E-03	9.03E+01	9.75E+01	1.23E-03	3.70E+01	4.13E+01	3.98E-04	1.22E+01	1.37E+01
CNC-D	3.31E-03	9.47E+01	1.02E+02	1.29E-03	3.41E+01	3.56E+01	3.87E-04	1.17E+01	1.22E+01
CNC-C	1.06E-02	1.55E+02	1.73E+02	3.77E-03	5.55E+01	5.20E+01	1.17E-03	1.91E+01	1.97E+01
GAL-D	5.03E-03	1.33E+02	1.38E+02	2.01E-03	4.90E+01	4.92E+01	5.35E-04	1.66E+01	1.92E+01
GAL-C	1.37E-03	8.70E+01	1.16E+02	6.77E-04	3.72E+01	3.93E+01	2.01E-04	1.30E+01	1.38E+01
JAC-D	1.29E-03	7.23E+01	7.86E+01	5.59E-04	2.78E+01	3.07E+01	1.45E-04	1.01E+01	1.05E+01
JAC-C	1.26E-03	6.40E+01	6.77E+01	5.28E-04	2.45E+01	2.69E+01	1.55E-04	8.55E+00	9.22E+00
LOS-D	NOT-FOUND	2.67E+02	2.70E+02	NOT-FOUND	1.02E+02	1.04E+02	NOT-FOUND	3.32E+01	3.64E+01
LOS-C	3.66E-03	2.19E+02	2.41E+02	1.38E-03	9.72E+01	9.84E+01	5.13E-04	3.14E+01	3.12E+01
MOT-D	5.03E-04	2.46E+01	2.63E+01	1.80E-04	8.87E+00	9.48E+00	6.25E-05	2.90E+00	2.95E+00
NEW-D	1.20E-02	5.87E+02	6.37E+02	4.24E-03	2.42E+02	2.52E+02	1.34E-03	8.29E+01	8.68E+01
NEW-C	3.13E-02	9.41E+02	1.08E+03	1.19E-02	3.86E+02	3.99E+02	3.52E-03	1.33E+02	1.42E+02
NOR-D	3.40E-03	1.03E+02	1.10E+02	1.40E-03	4.04E+01	4.41E+01	4.59E-04	1.30E+01	1.39E+01
NOR-C	1.62E-03	9.02E+01	1.00E+02	7.13E-04	3.35E+01	3.56E+01	2.06E-04	1.16E+01	1.24E+01
PHI-D	8.45E-03	3.10E+02	3.32E+02	3.45E-03	1.15E+02	1.18E+02	1.00E-03	4.65E+01	5.03E+01
PHI-C	5.07E-03	2.86E+02	2.98E+02	2.03E-03	1.05E+02	1.08E+02	6.95E-04	4.13E+01	4.63E+01
POR-D	3.16E-03	1.09E+02	1.13E+02	1.18E-03	4.62E+01	4.90E+01	3.55E-04	1.40E+01	1.59E+01
POR-C	3.48E-03	1.01E+02	1.04E+02	1.35E-03	3.55E+01	4.37E+01	4.02E-04	1.19E+01	1.46E+01
SAV-D	5.26E-03	1.26E+02	1.28E+02	2.10E-03	5.56E+01	5.98E+01	6.05E-04	2.04E+01	2.16E+01
SAV-C	8.01E-04	4.37E+01	4.44E+01	3.33E-04	1.59E+01	1.72E+01	9.87E-05	5.65E+00	5.42E+00
SEA-C	8.69E-04	5.53E+01	5.99E+01	3.54E-04	2.10E+01	2.29E+01	1.12E-04	7.43E+00	8.11E+00
TAC-D	1.55E-03	8.36E+01	8.67E+01	7.01E-04	3.51E+01	3.60E+01	2.09E-04	1.19E+01	1.23E+01
TAC-C	1.87E-03	9.69E+01	1.01E+02	7.23E-04	3.65E+01	4.21E+01	2.20E-04	1.29E+01	1.52E+01
WIL-D	4.47E-03	7.09E+01	7.65E+01	1.79E-03	2.75E+01	2.98E+01	5.10E-04	9.33E+00	1.08E+01
WIL-C	1.03E-03	2.25E+01	2.79E+01	3.89E-04	8.70E+00	9.96E+00	1.18E-04	3.00E+00	3.11E+00
CHN-D	7.70E-04	3.69E+01	3.91E+01	3.04E-04	1.36E+01	1.42E+01	9.88E-05	5.22E+00	5.46E+00

Total Cancer Fatalities, 0-80 KM

		BR-2			RHF			TRIGA	
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	4.33E-05	1.98E+00	2.24E+00	1.63E-05	7.81E-01	8.41E-01	5.50E-06	2.67E-01	2.89E-01
CHA-C	1.30E-04	3.96E+00	4.27E+00	7.14E-05	1.61E+00	1.69E+00	1.60E-05	4.94E-01	5.80E-01
CNC-D	1.43E-04	4.07E+00	4.38E+00	5.84E-05	1.28E+00	1.35E+00	1.60E-05	5.30E-01	5.55E-01
CNC-C	4.60E-04	6.20E+00	6.23E+00	1.80E-04	2.55E+00	2.59E+00	5.25E-05	8.80E-01	8.78E-01
GAL-D	2.07E-04	4.93E+00	5.12E+00	7.64E-05	1.96E+00	2.07E+00	2.18E-05	7.00E-01	7.31E-01
GAL-C	7.04E-05	3.88E+00	4.09E+00	2.89E-05	1.49E+00	1.54E+00	7.95E-06	5.73E-01	5.88E-01
JAC-D	5.80E-05	3.10E+00	3.21E+00	2.38E-05	1.12E+00	1.15E+00	6.67E-06	3.91E-01	4.34E-01
JAC-C	6.04E-05	2.71E+00	2.87E+00	2.29E-05	1.08E+00	1.14E+00	6.50E-06	3.53E-01	3.75E-01
LOS-D	NOT-FOUND	1.03E+01	1.05E+01	NOT-FOUND	4.49E+00	4.52E+00	NOT-FOUND	1.45E+00	1.58E+00
LOS-C	1.98E-04	9.81E+00	1.01E+01	7.39E-05	3.39E+00	3.90E+00	2.08E-05	1.18E+00	1.19E+00
MOT-D	2.32E-05	1.22E+00	1.33E+00	8.61E-06	4.08E-01	4.42E-01	2.67E-06	1.43E-01	1.47E-01
NEW-D	4.40E-04	2.46E+01	2.58E+01	1.72E-04	1.10E+01	1.15E+01	5.49E-05	3.48E+00	3.83E+00
NEW-C	1.29E-03	3.89E+01	4.36E+01	5.34E-04	1.47E+01	1.67E+01	1.40E-04	5.75E+00	6.28E+00
NOR-D	1.55E-04	4.23E+00	4.63E+00	6.51E-05	1.62E+00	1.81E+00	1.85E-05	5.99E-01	6.50E-01
NOR-C	7.23E-05	3.59E+00	3.97E+00	3.08E-05	1.39E+00	1.43E+00	8.46E-06	5.25E-01	5.47E-01
PHI-D	3.54E-04	1.18E+01	1.23E+01	1.29E-04	5.18E+00	5.55E+00	3.88E-05	1.90E+00	2.05E+00
PHI-C	2.03E-04	1.22E+01	1.12E+01	9.95E-05	4.74E+00	4.93E+00	2.85E-05	1.78E+00	1.85E+00
POR-D	1.47E-04	4.90E+00	5.16E+00	6.01E-05	1.96E+00	2.03E+00	1.61E-05	6.89E-01	7.13E-01
POR-C	1.48E-04	3.78E+00	4.71E+00	6.08E-05	1.56E+00	1.84E+00	1.63E-05	5.45E-01	6.19E-01
SAV-D	2.23E-04	5.68E+00	6.22E+00	1.01E-04	2.20E+00	2.45E+00	2.41E-05	7.91E-01	8.82E-01
SAV-C	3.52E-05	1.79E+00	1.93E+00	1.28E-05	6.84E-01	7.04E-01	3.71E-06	2.45E-01	2.62E-01
SEA-C	3.73E-05	2.41E+00	2.61E+00	1.40E-05	9.06E-01	9.68E-01	4.16E-06	3.17E-01	3.47E-01
TAC-D	7.55E-05	3.60E+00	3.74E+00	3.03E-05	1.32E+00	1.42E+00	8.41E-06	5.55E-01	5.74E-01
TAC-C	8.26E-05	3.94E+00	4.73E+00	3.19E-05	1.59E+00	1.87E+00	9.47E-06	5.25E-01	6.20E-01
WIL-D	1.99E-04	2.90E+00	3.25E+00	7.68E-05	1.17E+00	1.21E+00	2.05E-05	3.98E-01	4.27E-01
WIL-C	4.89E-05	1.04E+00	1.16E+00	1.96E-05	4.13E-01	4.66E-01	5.15E-06	1.45E-01	1.55E-01
CHN-D	3.33E-05	1.55E+00	1.70E+00	1.32E-05	6.28E-01	7.15E-01	3.67E-06	2.19E-01	2.32E-01

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-33 Peak Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	2.82E-03	1.04E+02	1.10E+02	1.12E-03	4.07E+01	4.32E+01	3.41E-04	1.43E+01	1.51E+01
CHA-C	4.41E-03	2.12E+02	2.31E+02	1.76E-03	8.56E+01	9.34E+01	5.23E-04	3.00E+01	3.27E+01
CNC-D	3.35E-03	1.02E+02	1.11E+02	1.33E-03	4.03E+01	4.40E+01	4.00E-04	1.42E+01	1.55E+01
CNC-C	1.42E-02	6.71E+02	7.27E+02	5.70E-03	2.66E+02	2.88E+02	1.72E-03	9.34E+01	1.01E+02
GAL-D	5.60E-03	2.33E+02	2.54E+02	2.22E-03	9.59E+01	1.05E+02	6.69E-04	3.36E+01	3.66E+01
GAL-C	2.09E-03	1.85E+02	2.02E+02	8.28E-04	7.23E+01	7.89E+01	2.56E-04	2.53E+01	2.76E+01
JAC-D	2.15E-03	1.10E+02	1.20E+02	8.53E-04	4.28E+01	4.66E+01	2.61E-04	1.50E+01	1.63E+01
JAC-C	1.90E-03	1.12E+02	1.23E+02	7.52E-04	4.59E+01	5.01E+01	2.31E-04	1.61E+01	1.76E+01
LOS-D	1.30E-02	3.94E+02	4.29E+02	5.20E-03	1.56E+02	1.70E+02	1.54E-03	5.49E+01	5.98E+01
LOS-C	5.97E-03	3.47E+02	3.76E+02	2.39E-03	1.37E+02	1.49E+02	7.21E-04	4.83E+01	5.23E+01
MOT-D	7.72E-04	4.61E+01	5.03E+01	2.98E-04	1.71E+01	1.86E+01	9.74E-05	5.88E+00	6.42E+00
NEW-D	1.86E-02	1.13E+03	1.24E+03	7.44E-03	4.48E+02	4.89E+02	2.24E-03	1.58E+02	1.72E+02
NEW-C	3.41E-02	1.33E+03	1.45E+03	1.36E-02	5.25E+02	5.73E+02	4.01E-03	1.85E+02	2.02E+02
NOR-D	4.29E-03	1.66E+02	1.81E+02	1.71E-03	6.49E+01	7.06E+01	5.08E-04	2.27E+01	2.47E+01
NOR-C	2.78E-03	1.64E+02	1.78E+02	1.11E-03	6.44E+01	7.00E+01	3.36E-04	2.26E+01	2.45E+01
PHI-D	1.13E-02	7.15E+02	7.80E+02	4.52E-03	2.82E+02	3.08E+02	1.36E-03	9.91E+01	1.08E+02
PHI-C	8.77E-03	4.87E+02	5.31E+02	3.50E-03	1.92E+02	2.10E+02	1.06E-03	6.75E+01	7.36E+01
POR-D	3.85E-03	1.69E+02	1.85E+02	1.54E-03	6.69E+01	7.30E+01	4.64E-04	2.35E+01	2.57E+01
POR-C	3.94E-03	1.70E+02	1.85E+02	1.57E-03	6.66E+01	7.27E+01	4.67E-04	2.34E+01	2.55E+01
SAV-D	6.18E-03	2.39E+02	2.60E+02	2.46E-03	9.64E+01	1.05E+02	7.32E-04	3.38E+01	3.69E+01
SAV-C	1.43E-03	7.65E+01	8.00E+01	5.66E-04	2.94E+01	3.07E+01	1.75E-04	1.03E+01	1.07E+01
SEA-C	9.93E-04	5.62E+01	6.13E+01	3.93E-04	2.14E+01	2.33E+01	1.22E-04	7.44E+00	8.11E+00
TAC-D	2.67E-03	1.18E+02	1.29E+02	1.06E-03	4.66E+01	5.09E+01	3.23E-04	1.64E+01	1.79E+01
TAC-C	3.13E-03	1.70E+02	1.85E+02	1.25E-03	6.64E+01	7.25E+01	3.78E-04	2.33E+01	2.54E+01
WIL-D	5.50E-03	1.49E+02	1.63E+02	2.20E-03	5.91E+01	6.44E+01	6.51E-04	2.08E+01	2.27E+01
WIL-C	1.18E-03	3.28E+01	3.58E+01	4.71E-04	1.29E+01	1.41E+01	1.41E-04	4.57E+00	4.99E+00
CHN-D	1.76E-03	6.83E+01	7.43E+01	6.97E-04	2.64E+01	2.87E+01	2.14E-04	9.20E+00	1.00E+01

Total Cancer Fatalities, 0-80 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.20E-04	4.41E+00	4.69E+00	4.80E-05	1.72E+00	1.83E+00	1.37E-05	6.02E-01	6.39E-01
CHA-C	1.95E-04	8.90E+00	9.71E+00	7.83E-05	3.60E+00	3.93E+00	2.17E-05	1.26E+00	1.38E+00
CNC-D	1.49E-04	4.31E+00	4.68E+00	5.96E-05	1.68E+00	1.83E+00	1.68E-05	5.90E-01	6.44E-01
CNC-C	6.01E-04	2.80E+01	3.03E+01	2.42E-04	1.11E+01	1.20E+01	6.84E-05	3.89E+00	4.22E+00
GAL-D	2.48E-04	9.97E+00	1.09E+01	9.90E-05	4.08E+00	4.45E+00	2.79E-05	1.43E+00	1.55E+00
GAL-C	9.02E-05	7.89E+00	8.61E+00	3.57E-05	3.07E+00	3.35E+00	1.05E-05	1.07E+00	1.17E+00
JAC-D	9.25E-05	4.71E+00	5.12E+00	3.68E-05	1.82E+00	1.98E+00	1.07E-05	6.37E-01	6.93E-01
JAC-C	8.20E-05	4.71E+00	5.13E+00	3.26E-05	1.93E+00	2.11E+00	9.47E-06	6.77E-01	7.38E-01
LOS-D	5.75E-04	1.64E+01	1.79E+01	2.31E-04	6.50E+00	7.08E+00	6.37E-05	2.29E+00	2.49E+00
LOS-C	2.52E-04	1.45E+01	1.57E+01	1.01E-04	5.73E+00	6.20E+00	2.87E-05	2.01E+00	2.18E+00
MOT-D	3.49E-05	2.10E+00	2.29E+00	1.34E-05	7.69E-01	8.39E-01	4.24E-06	2.65E-01	2.88E-01
NEW-D	7.88E-04	4.72E+01	5.16E+01	3.17E-04	1.87E+01	2.04E+01	8.94E-05	6.56E+00	7.16E+00
NEW-C	1.50E-03	5.53E+01	6.04E+01	6.06E-04	2.19E+01	2.39E+01	1.66E-04	7.69E+00	8.39E+00
NOR-D	1.89E-04	7.09E+00	7.71E+00	7.62E-05	2.75E+00	2.99E+00	2.10E-05	9.63E-01	1.05E+00
NOR-C	1.19E-04	6.92E+00	7.52E+00	4.75E-05	2.71E+00	2.94E+00	1.35E-05	9.50E-01	1.03E+00
PHI-D	4.79E-04	2.99E+01	3.26E+01	1.93E-04	1.18E+01	1.29E+01	5.44E-05	4.14E+00	4.52E+00
PHI-C	3.71E-04	2.04E+01	2.23E+01	1.49E-04	8.03E+00	8.77E+00	4.23E-05	2.82E+00	3.08E+00
POR-D	1.68E-04	7.05E+00	7.70E+00	6.74E-05	2.79E+00	3.04E+00	1.87E-05	9.80E-01	1.07E+00
POR-C	1.74E-04	7.18E+00	7.84E+00	7.00E-05	2.81E+00	3.06E+00	1.94E-05	9.84E-01	1.07E+00
SAV-D	2.74E-04	1.00E+01	1.09E+01	1.10E-04	4.07E+00	4.44E+00	3.04E-05	1.43E+00	1.55E+00
SAV-C	6.15E-05	3.32E+00	3.48E+00	2.44E-05	1.27E+00	1.33E+00	7.14E-06	4.42E-01	4.62E-01
SEA-C	4.27E-05	2.47E+00	2.69E+00	1.69E-05	9.33E-01	1.02E+00	4.99E-06	3.24E-01	3.53E-01
TAC-D	1.14E-04	5.03E+00	5.49E+00	4.54E-05	1.95E+00	2.12E+00	1.31E-05	6.83E-01	7.45E-01
TAC-C	1.33E-04	7.18E+00	7.84E+00	5.34E-05	2.80E+00	3.06E+00	1.51E-05	9.82E-01	1.07E+00
WIL-D	2.43E-04	6.24E+00	6.80E+00	9.80E-05	2.46E+00	2.69E+00	2.69E-05	8.70E-01	9.48E-01
WIL-C	5.22E-05	1.41E+00	1.54E+00	2.10E-05	5.42E-01	5.92E-01	5.94E-06	1.93E-01	2.10E-01
CHN-D	7.30E-05	2.95E+00	3.21E+00	2.90E-05	1.13E+00	1.23E+00	8.51E-06	3.95E-01	4.29E-01

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-33 Peak Results, Variable Meteorology (Continued)

Individual Center-line EDE Whole Body Dose, 0-1.6 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
CHA-C	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
CNC-D	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
CNC-C	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
GAL-D	3.66E-06	5.34E-02	5.82E-02	1.46E-06	2.11E-02	2.31E-02	4.06E-07	7.43E-03	8.10E-03
GAL-C	3.66E-06	5.34E-02	5.82E-02	1.46E-06	2.11E-02	2.31E-02	4.06E-07	7.43E-03	8.10E-03
JAC-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
JAC-C	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
LOS-D	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
LOS-C	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
MOT-D	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
NEW-D	3.66E-06	4.12E-02	4.50E-02	1.46E-06	1.63E-02	1.78E-02	4.06E-07	5.74E-03	6.26E-03
NEW-C	3.66E-06	4.12E-02	4.50E-02	1.46E-06	1.63E-02	1.78E-02	4.06E-07	5.74E-03	6.26E-03
NOR-D	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
NOR-C	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
PHI-D	3.66E-06	6.06E-02	6.61E-02	1.46E-06	2.40E-02	2.62E-02	4.06E-07	8.43E-03	9.20E-03
PHI-C	3.66E-06	6.06E-02	6.61E-02	1.46E-06	2.40E-02	2.62E-02	4.06E-07	8.43E-03	9.20E-03
POR-D	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
POR-C	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
SAV-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
SAV-C	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
SEA-C	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
TAC-D	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
TAC-C	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
WIL-D	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
WIL-C	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
CHN-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03

Individual Center-line Cancer Risk, 0-1.6 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
CHA-C	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
CNC-D	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
CNC-C	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
GAL-D	1.79E-07	2.23E-03	2.43E-03	7.29E-08	8.80E-04	9.60E-04	1.84E-08	3.09E-04	3.37E-04
GAL-C	1.79E-07	2.23E-03	2.43E-03	7.29E-08	8.80E-04	9.60E-04	1.84E-08	3.09E-04	3.37E-04
JAC-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
JAC-C	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
LOS-D	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
LOS-C	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
MOT-D	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
NEW-D	1.79E-07	1.72E-03	1.88E-03	7.29E-08	6.80E-04	7.42E-04	1.84E-08	2.39E-04	2.61E-04
NEW-C	1.79E-07	1.72E-03	1.88E-03	7.29E-08	6.80E-04	7.42E-04	1.84E-08	2.39E-04	2.61E-04
NOR-D	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
NOR-C	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
PHI-D	1.79E-07	2.53E-03	2.76E-03	7.29E-08	9.98E-04	1.09E-03	1.84E-08	3.51E-04	3.83E-04
PHI-C	1.79E-07	2.53E-03	2.76E-03	7.29E-08	9.98E-04	1.09E-03	1.84E-08	3.51E-04	3.83E-04
POR-D	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
POR-C	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
SAV-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
SAV-C	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
SEA-C	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
TAC-D	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
TAC-C	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
WIL-D	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
WIL-C	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
CHN-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-34 Probability of Peak Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05
CHA-C	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06
CNC-D	8.47E-04	1.18E-05	1.18E-05	8.47E-04	1.18E-05	1.18E-05	8.47E-04	1.18E-05	1.18E-05
CNC-C	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06
GAL-D	7.80E-06	9.75E-06	9.75E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06
GAL-C	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06
JAC-D	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06
JAC-C	6.08E-06	8.06E-06	8.06E-06	6.08E-06	8.06E-06	8.06E-06	6.08E-06	8.06E-06	8.06E-06
LOS-D	1.83E-03	3.42E-06	3.42E-06	1.83E-03	3.42E-06	3.42E-06	1.83E-03	3.42E-06	3.42E-06
LOS-C	4.91E-06	2.81E-06	2.81E-06	4.91E-06	2.81E-06	2.81E-06	4.91E-06	2.81E-06	2.81E-06
MOT-D	1.67E-05	2.76E-05	2.76E-05	1.67E-05	2.76E-05	2.76E-05	1.67E-05	2.76E-05	2.76E-05
NEW-D	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05
NEW-C	2.50E-04	7.65E-05	7.65E-05	2.50E-04	7.65E-05	7.65E-05	2.50E-04	7.65E-05	7.65E-05
NOR-D	3.51E-04	9.62E-06	9.62E-06	3.51E-04	9.62E-06	9.62E-06	3.51E-04	9.62E-06	9.62E-06
NOR-C	1.07E-05	1.61E-05	1.61E-05	1.07E-05	1.61E-05	1.61E-05	1.07E-05	1.61E-05	1.61E-05
PHI-D	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06
PHI-C	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05
POR-D	1.26E-05	1.09E-05	1.09E-05	1.26E-05	1.09E-05	1.09E-05	1.26E-05	1.09E-05	1.09E-05
POR-C	3.19E-04	1.09E-05	1.09E-05	3.19E-04	1.09E-05	1.09E-05	3.19E-04	1.09E-05	1.09E-05
SAV-D	1.13E-05	6.22E-06	6.22E-06	1.13E-05	6.22E-06	6.22E-06	1.13E-05	6.22E-06	6.22E-06
SAV-C	1.30E-05	1.14E-05	1.14E-05	1.30E-05	1.14E-05	1.14E-05	1.30E-05	1.14E-05	1.14E-05
SEA-C	1.36E-04	6.79E-04	6.79E-04	1.36E-04	6.79E-04	6.79E-04	1.36E-04	9.80E-04	9.80E-04
TAC-D	5.33E-06	1.14E-05	1.14E-05	5.33E-06	1.14E-05	1.14E-05	5.33E-06	1.14E-05	1.14E-05
TAC-C	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05
WIL-D	3.26E-04	1.16E-04	1.16E-04	3.26E-04	1.16E-04	1.16E-04	3.26E-04	1.16E-04	1.16E-04
WIL-C	3.04E-04	1.08E-04	1.08E-04	3.04E-04	1.08E-04	1.08E-04	3.04E-04	1.08E-04	1.08E-04
CHN-D	6.27E-06	3.89E-06	3.89E-06	6.27E-06	3.89E-06	3.89E-06	6.27E-06	3.89E-06	3.89E-06

Total Cancer Fatalities, 0-80 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05
CHA-C	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06
CNC-D	8.47E-04	5.08E-04	5.08E-04	8.47E-04	1.18E-05	1.18E-05	8.47E-04	1.18E-05	1.18E-05
CNC-C	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06
GAL-D	7.80E-06	9.75E-06	9.75E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06
GAL-C	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06
JAC-D	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06
JAC-C	6.08E-06	8.06E-06	8.06E-06	6.08E-06	8.06E-06	8.06E-06	6.08E-06	8.06E-06	8.06E-06
LOS-D	1.83E-03	3.42E-06	3.42E-06	1.83E-03	3.42E-06	3.42E-06	1.83E-03	3.42E-06	3.42E-06
LOS-C	4.91E-06	2.81E-06	2.81E-06	4.91E-06	2.81E-06	2.81E-06	4.91E-06	2.81E-06	2.81E-06
MOT-D	1.67E-05	2.76E-05	2.76E-05	1.67E-05	2.76E-05	2.76E-05	1.67E-05	2.76E-05	2.76E-05
NEW-D	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05
NEW-C	2.50E-04	7.65E-05	7.65E-05	2.50E-04	7.65E-05	7.65E-05	2.50E-04	7.65E-05	7.65E-05
NOR-D	3.51E-04	9.62E-06	9.62E-06	3.51E-04	9.62E-06	9.62E-06	3.51E-04	9.62E-06	9.62E-06
NOR-C	1.07E-05	1.61E-05	1.61E-05	1.07E-05	1.61E-05	1.61E-05	1.07E-05	1.61E-05	1.61E-05
PHI-D	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06
PHI-C	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05
POR-D	2.98E-04	1.09E-05	1.09E-05	2.98E-04	1.09E-05	1.09E-05	2.98E-04	1.09E-05	1.09E-05
POR-C	3.19E-04	1.09E-05	1.09E-05	3.19E-04	1.09E-05	1.09E-05	3.19E-04	1.09E-05	1.09E-05
SAV-D	1.13E-05	6.22E-06	6.22E-06	1.13E-05	6.22E-06	6.22E-06	1.13E-05	6.22E-06	6.22E-06
SAV-C	1.30E-05	1.14E-05	1.14E-05	1.30E-05	1.14E-05	1.14E-05	1.30E-05	1.14E-05	1.14E-05
SEA-C	1.36E-04	6.79E-04	6.79E-04	1.36E-04	6.79E-04	6.79E-04	1.36E-04	6.79E-04	6.79E-04
TAC-D	5.33E-06	1.08E-05	1.08E-05	5.33E-06	1.08E-05	1.08E-05	5.33E-06	1.14E-05	1.14E-05
TAC-C	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05
WIL-D	3.26E-04	1.16E-04	1.16E-04	3.26E-04	1.16E-04	1.16E-04	3.26E-04	1.16E-04	1.16E-04
WIL-C	3.04E-04	1.27E-05	1.27E-05	3.04E-04	1.08E-04	1.08E-04	3.04E-04	1.08E-04	1.08E-04
CHN-D	6.27E-06	3.89E-06	3.89E-06	6.27E-06	3.89E-06	3.89E-06	6.27E-06	3.89E-06	3.89E-06

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-34 Probability of Peak Results, Variable Meteorology (Continued)

Individual Center-line EDE Whole Body Dose, 0-1.6 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CHA-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CNC-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
CNC-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
GAL-D	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
GAL-C	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
JAC-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
JAC-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
LOS-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
LOS-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
MOT-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NEW-D	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NEW-C	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NOR-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NOR-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
PHI-D	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
PHI-C	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
POR-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
POR-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
SAV-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SAV-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SEA-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
WIL-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
WIL-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
CHN-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03

Individual Center-line Cancer Risk, 0-1.6 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CHA-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CNC-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
CNC-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
GAL-D	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
GAL-C	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
JAC-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
JAC-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
LOS-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
LOS-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
MOT-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NEW-D	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NEW-C	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NOR-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NOR-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
PHI-D	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
PHI-C	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
POR-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
POR-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
SAV-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SAV-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SEA-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
WIL-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
WIL-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
CHN-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

population within 80.5 km (50 mi) of the Elizabeth channel accident location is about 16 million people and typical plumes are about two compass sectors wide, a typical accident plume might expose about two million people to radiation. Thus, for the largest mean result obtained, an average 50-year individual dose over the total exposed populations is about 6,900 person-rem/2,000,000 people = 0.0035 rem per person, which is 5,300 times smaller than the average dose (15 rem) people normally receive from natural, medical, and occupational exposures during the same period of time (BEIR, 1990).

Due to variable weather conditions, the calculated accident consequences vary over a range of values of approximately two orders of magnitude. Quantile values are one means used to indicate how much variation exists among the quantified consequences. The 99.9th quantile values presented in Table D-32 represent the accident consequences that are expected no more than 0.1 percent of the time, that is 99.9 percent of the time the accident consequences will be less than the values presented here. The 99.9th quantile values range from 0.00625 rem (at the MOTSU dock, TRIGA fuel, release category 4) to 108,000 rem (at the Elizabeth channel, BR-2 fuel, release category 6). These results are about three orders of magnitude less likely than the mean, but are less than two orders of magnitude higher than the mean results. (In some cases a 99.9th quantile value is listed as "NOT FOUND." In these instances the peak values, discussed in the following paragraph, occur with a probability of greater than 0.001).

Table D-33 shows that the largest value (peak result) calculated for population dose within 80.5 km (50 mi) of the accident location was 145,000 person-rem (1,450 person-Sv) and that this result was obtained for the Elizabeth channel calculation that used the BR-2 inventory, severity category 6 (EA6) release fractions, and New York City weather. Dividing by the two million people exposed by the accident gives an average 50-year individual dose over the exposed population of about 73 mrem, which is still 250 times smaller than a normal annual individual dose from background and medical exposure over the same period of time. In addition, Table D-34 shows that the probability of this result was 0.0000765 conditional on the accident having occurred. Since the probability of this accident occurring is about 6 x 10^{-10} per port call, the chance of having this result is much less than 1 x 10^{-10} per port call.

Table D-31 also shows that mean (expected) 50-year individual centerline doses at a distance of 0.8 km (0.5 mi) from the accident location [the midpoint of the 0-1.6 km or 0-1 mi computational interval] range from a low of 0.000006 rem (0.00000006 Sv) for the Norfolk and MOTSU calculations that used the TRIGA inventory, severity category 4 (EA4) release fractions, and Cape Hatteras weather to a high of 117 mrem (0.00117 Sv) for the Elizabeth calculations that used the BR-2 inventory, severity category 5 (EA5) release fractions, and New York City weather. Thus, the largest expected individual dose is 190 times smaller than a normal background medical and occupational individual dose during the same period (50 years), which suggests that the mean risk to a maximally exposed member of the general population is not of great concern. Note that the channel and dock values for centerline doses are the same for each port. This is because MACCS, in calculating centerline doses, develops the dose for a hypothetical person and so does not take into account population distribution. Therefore, the usually minor difference in position between the dock and channel does not result in different values. Table D-33 shows that the largest value (peak result) calculated for 50-year individual centerline dose for a person located 0.8 km (0.5 mi) from the accident location was 6.6 rem (0.066 Sv) and that this result was obtained for the Philadelphia calculations that used the BR-2 inventory, severity category 6 (EA6) release fractions, and Washington, DC, weather. This dose of 6.6 rem is less than half of the dose received due to background radiation over the same 50-year period. Table D-34 shows that the probability of this result is 0.00051 conditional on the accident having occurred. Thus, the chance per port call of the MEI receiving this 50-year dose is significantly less than 1 x 10^{-10}.

Table D-31 shows that the mean number of cancer deaths predicted to occur during the decades after the accident, among the populations located within 80.5 km (50 mi) of the accident site at the time of the accident, ranges from 0.00000041 for the MOTSU dock calculation that used the TRIGA inventory, severity category 4 (EA4) release fractions, and mean Cape Hatteras weather to 2.9 for the Elizabeth channel calculation that used the BR-2 inventory, severity category 5 (EA5) release fractions, and mean New York City weather. If all three of the cancer deaths predicted to occur as a result of the accident at the Elizabeth site should happen to occur in the same year, then the death rate among the two million people exposed to radiation by this accident would be 3/2,000,000 = 0.0000015 deaths per person year. Since the normal death rate due to all types of cancer is about 150 deaths per 100,000 people per year (World Almanac, 1992) or 0.0015 deaths per person year, the largest mean (expected) death rate for any base case calculation is 1,000 times smaller than the normal death rate due to cancer. Table D-33 shows that the largest number of cancer deaths obtained for any weather trial in any base case calculation was 60 and that this result was obtained for the Elizabeth channel calculation that used the BR-2 inventory, severity category 6 (EA6) release fractions, and New York City weather. Again, if all of these deaths were to occur in the same year in the future (a very improbable outcome), the death rate during that year among the population exposed to radiation by the accident would be 0.00003 or 50 times lower than the normal death rate due to cancer among this population. Table D-34 shows that the probability of this result is 0.000077 conditional on the occurrence of the accident or less than 1×10^{-10} per port call. Thus, even the worst case number of cancer deaths would be wholly undetectable in the exposed population by the best of epidemiological studies.

Figures D-56 and D-57 present Complementary Cumulative Distribution Functions for population dose and cancer fatalities among the population located within 80.5 km (50 mi) of the accident site for seven of the thirteen ports studied. Only seven were plotted to simplify the figure; these seven provide the full range of results. The figures display the range and probability (conditional on the occurrence of the accident) of these two consequence measures. Figure D-56 shows that any large accident (severity category 5 with the BR-2 inventory is a severe ship collision and fire accident) will lead to a population dose of 10 person-rem, that the values of the 99th quantile (probability of 0.01) range from about 2,000 person-rem to about 40,000 person-rem, and that the largest (peak) result calculated ranges from about 4,600 rem (MOTSU) to about 110,000 rem (Elizabeth). Figure D-57 shows that a large accident has about one chance in 10 (range of 0.002 to 0.6) of causing at least one cancer death among the exposed population in future years, that the values of the 99.9th quantile range from 1 cancer fatality to about 25 cancer deaths, and that the largest (peak) result calculated ranges from 2.1 to 47 deaths due to cancer during the years after the accident.

Figure D-58 presents an example of Complementary Cumulative Distribution Functions for population dose and cancer fatalities for the distance range 0 to 80.5 km (0 to 50 mi) for both the dock and channel locations at Charleston. This figure shows that the dock and channel Complementary Cumulative Distribution Functions for both population dose and cancer fatalities are quite similar, which is typical for all of the ports examined. This suggests that moving the coordinates of the origin of a population distribution a small distance (a few kilometers) has little effect on population dose or cancer fatalities among population located within 80.5 km (50 mi) of the accident location for severe accidents (Table D-28 lists the coordinates of the origins of the polar coordinate population distributions used in these calculations).

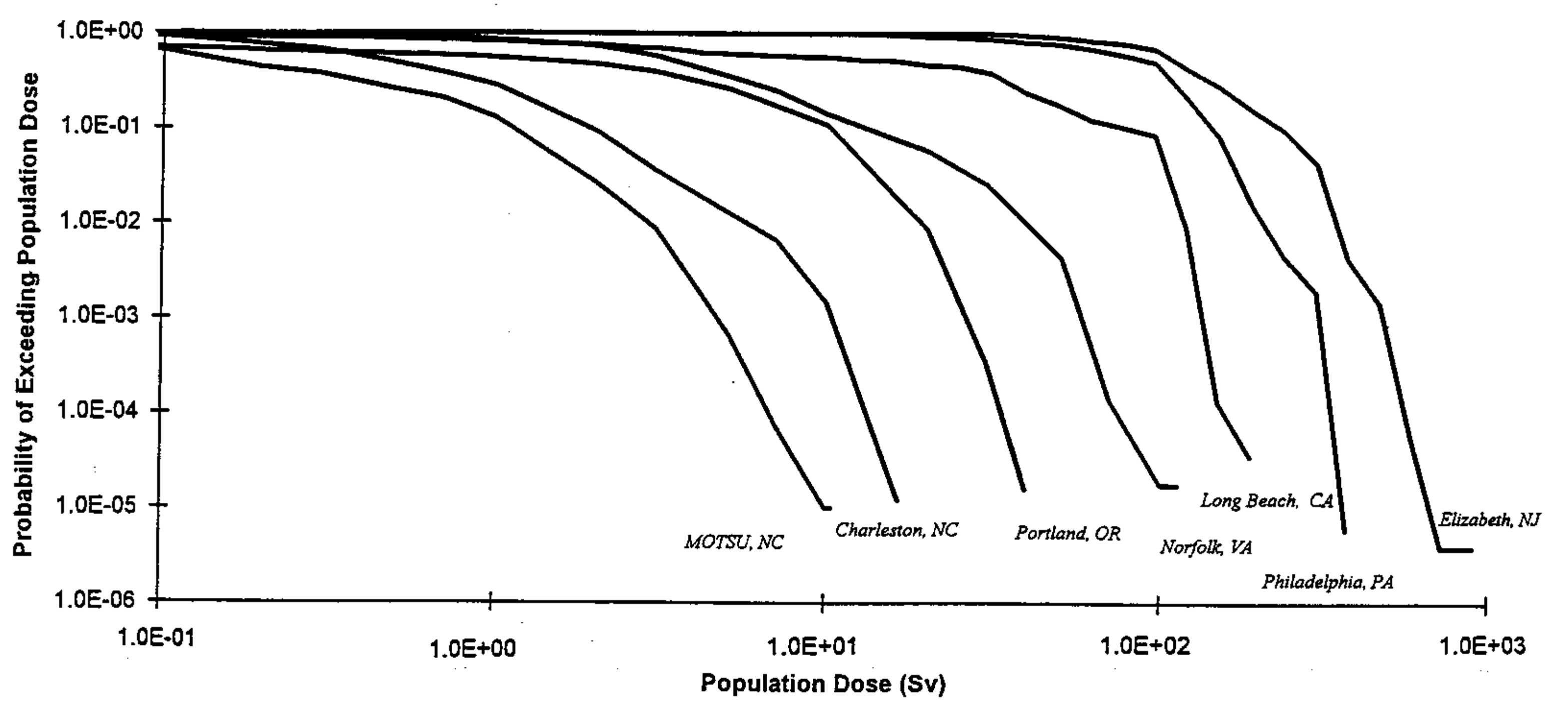

Figure D-56 Effective Dose Equivalent Whole Body Population Dose, 0-80 km (0-50 mi), Select Ports (at the Dock), Variable Meteorology, BR-2 Inventory, Severity Category 5 Releases

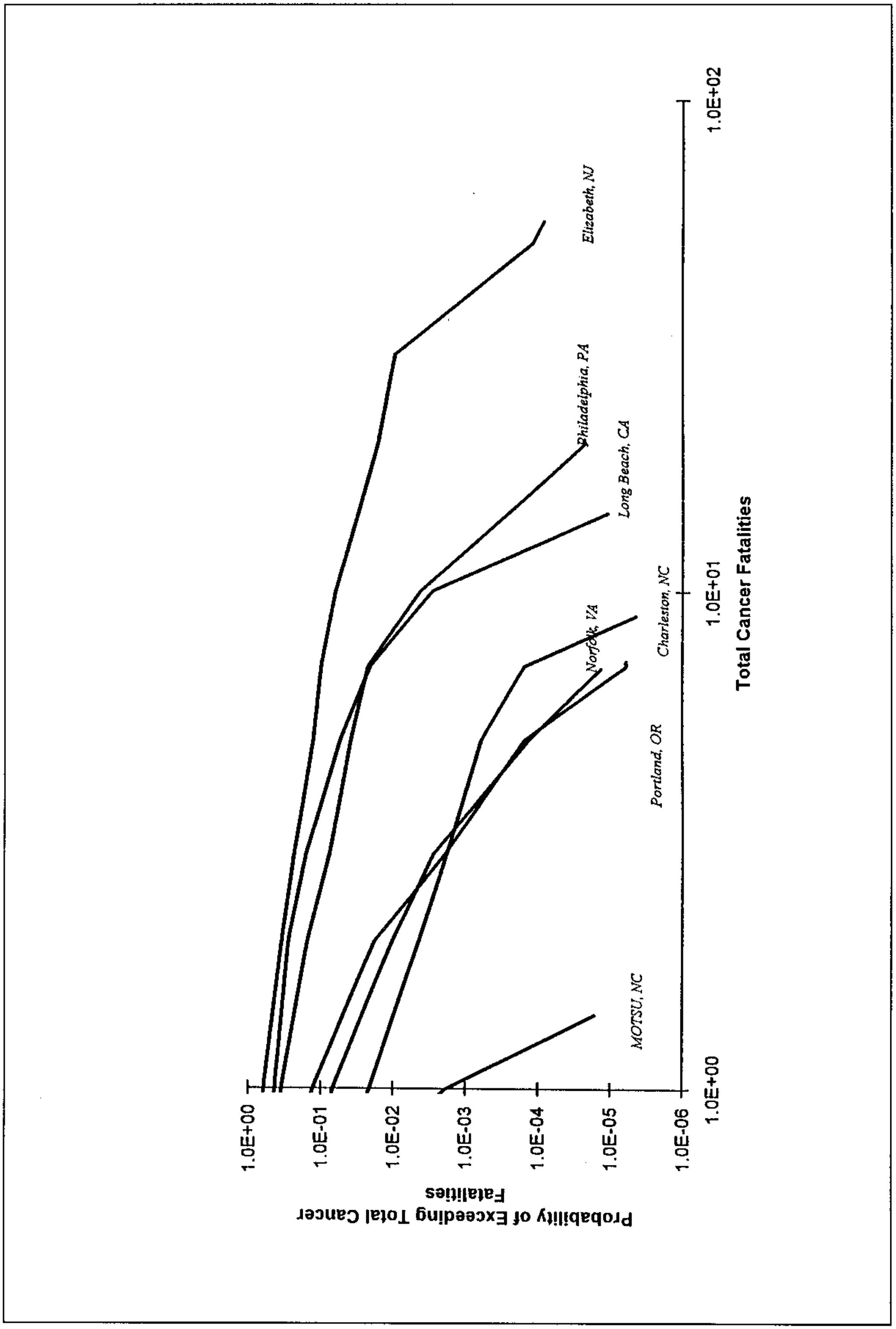

Figure D-57 Total Latent Cancer Fatalities, 0-80 km (0-50 mi), Select Ports (in the Channel), Variable Meteorology, BR-2 Inventory, Severity Category 5 Release

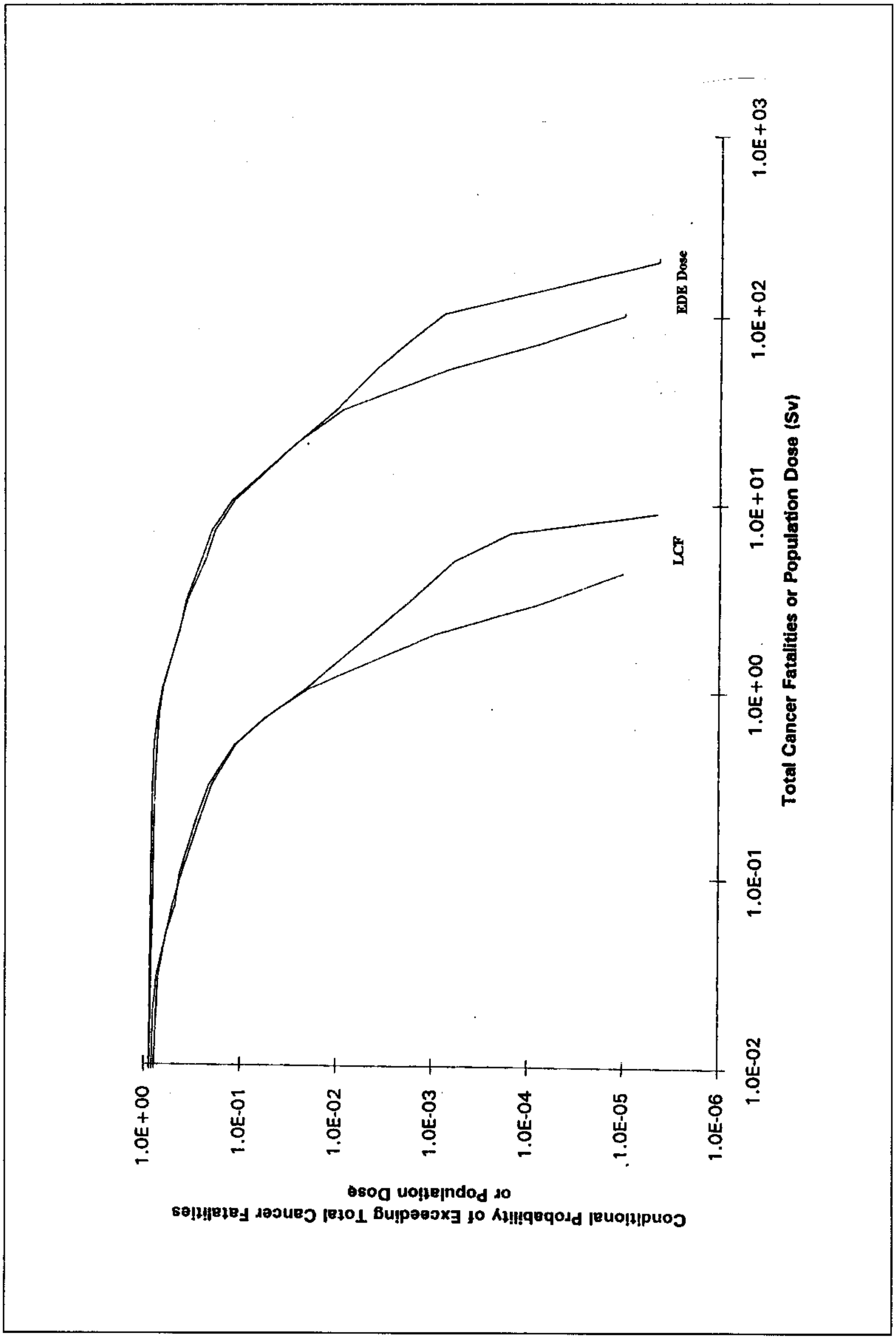

Figure D-58 Effective Equivalent Dose Whole Body Population Dose (Person-Sv) and Total Latent Cancer Fatalities, 0-80 km (0-50 mi), Charleston Dock and Channel Locations, Variable Meteorology, BR-2 Inventory, Severity Category 5 Release

D.5.4.3 Sensitivity Calculations

Two principal sensitivity calculations were performed to determine the sensitivity of the results to key parameters. First, the effect of using local less detailed meteorological data versus meteorological data recorded at a National Weather Service station located some distance from the port was evaluated. Second, the results of exceptionally high spent nuclear fuel temperatures were examined. Additionally, the sensitivity of changes in plume buoyancy, the size of the nuclide set, modal study release fractions, corrosion products release, and work force population were examined. The meteorological sensitivity calculations compared results obtained using variable meteorology recorded at a National Weather Service station away from the port to results obtained using constant meteorology recorded at the port. All other sensitivity calculations except the work force calculations were performed by modifying the Elizabeth base case channel calculation as was appropriate in order to examine the parameter of interest. The work force calculations were based on the Elizabeth dock site. All of the sensitivity calculations used the BR-2 inventory and all, except those that examined release fractions, used severity category 5 release fractions.

D.5.4.3.1 Variable vs. Constant Meteorology

Variable meteorology, which takes into account hourly changes of wind direction and speed, was used in the calculations that led to the results presented in this EIS. However, the detailed weather data required to support these calculations are not available in most ports, so detailed data from the most appropriate National Weather Service Station location possible were used. A sensitivity study was performed to better understand the effect of using detailed but not local weather data versus using local less-detailed port weather data. The local weather is called constant meteorology, to reflect the fact that the weather remains constant during the course of the accident, not varying on an hourly basis.

This study performed, for each port, a large number of constant meteorology calculations for each port, using the conditions and probabilities specified in the joint frequency distributions that were available for each port. Since joint frequency distributions specify for each compass sector the probability of occurrence of each of the six Pasquil-Gifford atmospheric stability classes with each of six windspeed ranges, 16 x 6 x 6 = 576 constant meteorology calculations could be performed, once assuming that it was raining and once assuming that it was not. Then, by cumulating the results of each set of approximately 1,150 constant meteorology single weather trial calculations (rain does not occur for all of the sets of conditions in the joint frequency distribution), a Complementary Cumulative Distribution Function could be constructed to compare with the complementary cumulative distribution function obtained using variable meteorology recorded at the nearest National Weather Service Station.

Table D-35 presents a sample joint frequency table for one of the ports examined during this EIS (Charleston). Tables D-36 and D-37 present the port wind rose and a probability of rain by stability class respectively for selected ports.

Constant meteorology calculations were performed as follows. For each port examined, two sets of constant meteorology calculations were performed. Both used the joint frequency distribution of windspeed (6 windspeed ranges) and stability class (6 stability classes) by wind direction (16 compass sectors) for the port being analyzed as the meteorological input data for MACCS. Each calculation was run two times, once for no rain and once assuming that it was raining throughout the entire simulation. Therefore, each MACCS constant meteorology calculation consisted of 6 x 6 x 16 x 2 = 1,152 constant meteorology trials. From these 1,152 trials, a complementary cumulative Distribution Function and a mean (expected result) was constructed for each consequence measure calculated.

Table D-35 1988-92 Summary Joint Frequency Table for Charleston, SC Port

A Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0003	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0003	.0003	.0002	.0003	.0001	.0002	.0001	.0001
4- 7	.0005	.0003	.0005	.0004	.0004	.0006	.0003	.0003	.0006	.0004	.0004	.0002	.0002	.0001	.0002	.0003
8-12	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

B Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0008	.0003	.0006	.0007	.0005	.0007	.0008	.0005	.0011	.0006	.0010	.0007	.0007	.0006	.0004	.0005
4- 7	.0018	.0013	.0017	.0019	.0023	.0020	.0017	.0013	.0031	.0016	.0023	.0017	.0018	.0011	.0013	.0007
8-12	.0021	.0013	.0021	.0025	.0025	.0014	.0013	.0008	.0016	.0013	.0013	.0010	.0013	.0012	.0016	.0012
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

C Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0002	.0002	.0003	.0003	.0003	.0003	.0003	.0003	.0004	.0003	.0005	.0005	.0003	.0002	.0001	.0001
4- 7	.0015	.0014	.0016	.0022	.0026	.0021	.0019	.0020	.0026	.0021	.0035	.0021	.0014	.0010	.0014	.0012
8-12	.0081	.0038	.0061	.0072	.0090	.0049	.0037	.0031	.0057	.0051	.0062	.0042	.0034	.0043	.0042	.0049
13-18	.0017	.0012	.0021	.0020	.0021	.0014	.0006	.0005	.0006	.0005	.0005	.0004	.0008	.0005	.0008	.0007
19-24	.0000	.0000	.0000	.0001	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

D Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0009	.0005	.0005	.0007	.0006	.0005	.0004	.0008	.0013	.0012	.0013	.0012	.0007	.0007	.0004	.0004
4- 7	.0045	.0030	.0037	.0027	.0028	.0026	.0022	.0044	.0094	.0079	.0093	.0056	.0042	.0039	.0026	.0022
8-12	.0196	.0151	.0165	.0112	.0108	.0070	.0047	.0061	.0168	.0216	.0201	.0124	.0108	.0075	.0066	.0083
13-18	.0140	.0179	.0145	.0082	.0133	.0096	.0058	.0058	.0084	.0080	.0057	.0047	.0051	.0035	.0034	.0036
19-24	.0009	.0019	.0020	.0007	.0020	.0023	.0010	.0004	.0003	.0000	.0000	.0001	.0001	.0001	.0001	.0000
>24	.0002	.0005	.0002	.0001	.0003	.0003	.0001	.0000	.0000	.0001	.0000	.0000	.0000	.0000	.0000	.0000

E Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
4- 7	.0127	.0071	.0088	.0047	.0033	.0023	.0021	.0025	.0050	.0061	.0094	.0066	.0052	.0049	.0036	.0051
8-12	.0063	.0072	.0085	.0059	.0067	.0058	.0032	.0030	.0038	.0066	.0043	.0021	.0019	.0013	.0011	.0016
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

F Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0090	.0076	.0081	.0059	.0052	.0039	.0035	.0057	.0086	.0076	.0101	.0054	.0054	.0036	.0032	.0035
4- 7	.0122	.0088	.0112	.0074	.0063	.0051	.0044	.0059	.0095	.0104	.0122	.0057	.0044	.0044	.0029	.0039
8-12	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

Table D-36 Wind Rose Table for Select Ports

1988-92 Summary Wind Rose Table For Charleston, SC Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0974	.0796	.0892	.0650	.0712	.0530	.0380	.0436	.0790	.0817	.0882	.0549	.0479	.0389	.0341	.0385

1988-92 Summary Wind Rose Table For Long Beach, CA Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0246	.0171	.0602	.3093	.1804	.0157	.0177	.0229	.0331	.0227	.0271	.0475	.1115	.0601	.0348	.0154

1988-92 Summary Wind Rose Table For Newark, NJ Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0784	.0725	.1015	.0871	.0854	.0639	.0788	.0559	.0832	.0786	.0442	.0273	.0231	.0304	.0452	.0447

1988-92 Summary Wind Rose Table For Norfolk, VA Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.1078	.0963	.1021	.0647	.0562	.0456	.0344	.0285	.0940	.0665	.0860	.0573	.0470	.0321	.0358	.0458

1988-92 Summary Wind Rose Table For Philadelphia, PA Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0682	.0440	.0950	.1118	.1281	.0913	.0715	.0568	.0669	.0266	.0275	.0639	.0545	.0284	.0278	.0378

1988-92 Summary Wind Rose Table For Portland, OR Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0936	.0551	.0337	.0315	.0756	.0956	.1163	.1054	.0704	.0187	.0171	.0225	.0638	.1126	.0576	.0304

1988-92 Summary Wind Rose Table For Wilmington, NC Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0744	.0804	.0994	.0798	.0747	.0378	.0417	.0435	.0955	.0780	.0699	.0488	.0549	.0351	.0411	.0451

Table D-37 Rainfall Data, Select Ports

Rainfall Data for the Charleston, SC Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.05000	0.00264
B	0.22400	0.00371
C	0.16322	0.00771
D	0.13860	0.11099
E	0.14740	0.01099
F	0.07941	0.00125

Rainfall Data for the Long Beach, CA Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.00000	0.00000
C	0.14375	0.00233
D	0.07837	0.03648
E	0.06596	0.00809
F	0.07083	0.00115

Rainfall Data for the Newark, NJ Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.05000	0.00059
C	0.08571	0.00648
D	0.08577	0.12139
E	0.08968	0.00971
F	0.05000	0.00153

Rainfall Data for the Norfolk, VA Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.09167	0.00371
C	0.10921	0.00771
D	0.47136	0.11099
E	0.12574	0.01099
F	0.05000	0.00125

Rainfall Data for the Philadelphia, PA Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.17500	0.00089
C	0.11250	0.00431
D	0.07520	0.12101
E	0.10682	0.00649
F	0.17500	0.00035

Rainfall Data for the Portland, OR Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.11250	0.00139
C	0.08125	0.01245
D	0.06172	0.15220
E	0.06493	0.01428
F	0.05000	0.00087

Rainfall Data for the Wilmington, NC Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.18235	0.00718
C	0.17500	0.01937
D	0.15048	0.12490
E	0.16295	0.02310
F	0.08571	0.00244

Table D-38 Comparison of Population Dose and Selected Ports Using Variable vs. Constant Meteorology for Category Accident of a BR-2 Fuel Cask

Site/Loc	EDE Whole Body Population Dose, 0-80 KM (Sv)				Total Cancer Fatalities, 0-80 KM			
	Mean		99.9th Quantile		Mean		99.9th Quantile	
	Var	Const	Var	Const	Var	Const	Var	Const
CHA-D	4.15E+00	3.06E+00	4.63E+01	2.13E+01	1.89E-01	1.29E-01	1.98E+00	8.43E-01
CHA-C	4.18E+00	3.41E+00	9.03E+01	3.71E+01	1.90E-01	1.43E-01	3.96E+00	2.01E+00
LOS-D	4.71E+01	3.44E+01	2.67E+02	1.19E+02	1.99E+00	1.44E+00	1.03E+01	5.35E+00
LOS-C	4.26E+01	3.31E+01	2.19E+02	8.16E+01	1.80E+00	1.38E+00	9.81E+00	3.43E+00
NEW-D	6.55E+01	5.47E+01	5.87E+02	2.32E+02	2.75E+00	2.28E+00	2.46E+01	9.54E+00
NEW-C	6.93E+01	5.89E+01	9.41E+02	NOT-FOUND	2.90E+00	2.46E+00	3.89E+01	NOT-FOUND
NOR-D	8.54E+00	8.88E+00	1.03E+02	7.26E+01	3.77E-01	3.72E-01	4.23E+00	3.07E+00
NOR-C	6.65E+00	6.76E+00	9.02E+01	3.51E+01	2.96E-01	2.83E-01	3.59E+00	1.34E+00
PHI-D	2.81E+01	2.53E+01	3.10E+02	NOT-FOUND	1.20E+00	1.06E+00	1.18E+01	1.34E+00
PHI-C	2.74E+01	2.01E+01	2.86E+02	5.91E+01	1.17E+00	8.40E-01	1.22E+01	2.45E+00
POR-D	1.17E+01	1.08E+01	1.09E+02	7.76E+01	5.18E-01	4.54E-01	4.90E+00	3.29E+00
POR-C	1.12E+01	8.76E+00	1.01E+02	3.88E+01	4.97E-01	3.68E-01	3.78E+00	1.51E+00
MOT-D	2.08E+00	1.02E+00	2.46E+01	NOT-FOUND	9.94E-02	4.37E-02	1.22E+00	1.51E+00
WIL-C	2.07E+00	1.05E+00	2.25E+01	5.47E+00	9.76E-02	4.49E-02	1.04E+00	2.22E-01

Table D-38 compares for seven ports the expected (mean) and 99.9th quantile values of population dose and cancer fatalities for the distance range 0 to 80.5 km (0-50 mi) obtained using variable meteorology to the values obtained using constant meteorology. Inspection of the table shows that the mean values for constant meteorology are quite similar to mean values for variable meteorology. For example, for population dose, the ratio of the variable meteorology result to the constant meteorology result has an average value and standard deviation of 1.31±0.31 for population dose and 1.34±0.41 for cancer fatalities. The MOTSU dock calculation yielded the largest values for these ratios, 2.04 for mean population dose and 2.27 for cancer fatalities. Thus, the use of meteorological data recorded at a nearby National Weather Service station yields expected (mean) values for population dose and cancer fatalities that are on average about 30 to 40 percent larger than the values obtained using constant meteorological conditions for each of the six Pasquil-Gifford atmospheric stability classes that were derived from data recorded at the harbor.

The 99.9th quantile values of population dose and cancer fatalities among the population that resides within 80.5 km (50 mi) of the harbor results agree less well for constant and variable meteorology. For several ports, the 99.9th quantile population dose is missing, ("not found"), for the constant meteorology calculation. This means that the probability of the largest result obtained for any of the 1,152 trials run during each constant meteorology calculation was larger than 0.001 for that particular calculation. For the locations that yielded a 99.9th quantile value for both the variable and constant meteorology calculation, the ratio of the 99.9th quantile variable meteorology result to the 99.9th quantile constant meteorology result has a value of 2.64±0.98 for population dose and 3.00±2.02 for cancer fatalities. The fact that the 99.9th quantile values obtained using variable meteorology are on average 2.5 to 3.0 times larger than the 99.9th quantile values obtained using constant meteorology suggests that the importance sampling scheme, used by MACCS to select weather sequences from a year of variable meteorological data, is able to find weather sequences that lead to adverse results that are not represented in the sets of constant meteorological conditions found in the joint frequency distributions of windspeed and atmospheric stability by wind direction that were recorded at the harbors. This is so because the occurrence of rain is usually the cause of peak results at some later time when the plume is passing over some downwind highly populated region. Thus, because rain at some downwind location was not modeled by the constant meteorology calculations, these results should differ significantly from those obtained using variable meteorology, especially for the higher quantiles of result distributions.

Figure D-59 presents, as an example, complementary cumulative distribution functions for Long Beach of the 50-year population dose and lifetime LCFs over the distance range from 0 to 80.5 km (0 to 50 mi) obtained using both variable and constant meteorology. All four calculations used the BR-2 inventory and severity category 5 release fractions. The dose calculation was performed for the dock location at Long Beach; and the LCF calculation was performed for the channel location. Inspection of the figures shows that the constant and variable meteorology complementary cumulative distribution functions are quite similar until the 90th quantile of the distributions are reached, and diverge increasingly as higher quantiles are passed, with the constant meteorology complementary cumulative distribution function generally falling off faster than the variable meteorology complementary cumulative distribution function (smaller consequence value at any consequence probability). Thus, the figures confirm the conclusion reached by inspection of Table D-38, that variable and constant meteorology yield quite similar estimates for mean results and that adverse meteorological conditions are more likely to be modeled if weather sequences are selected by importance sampling from a year of variable data than if constant meteorological conditions are used.

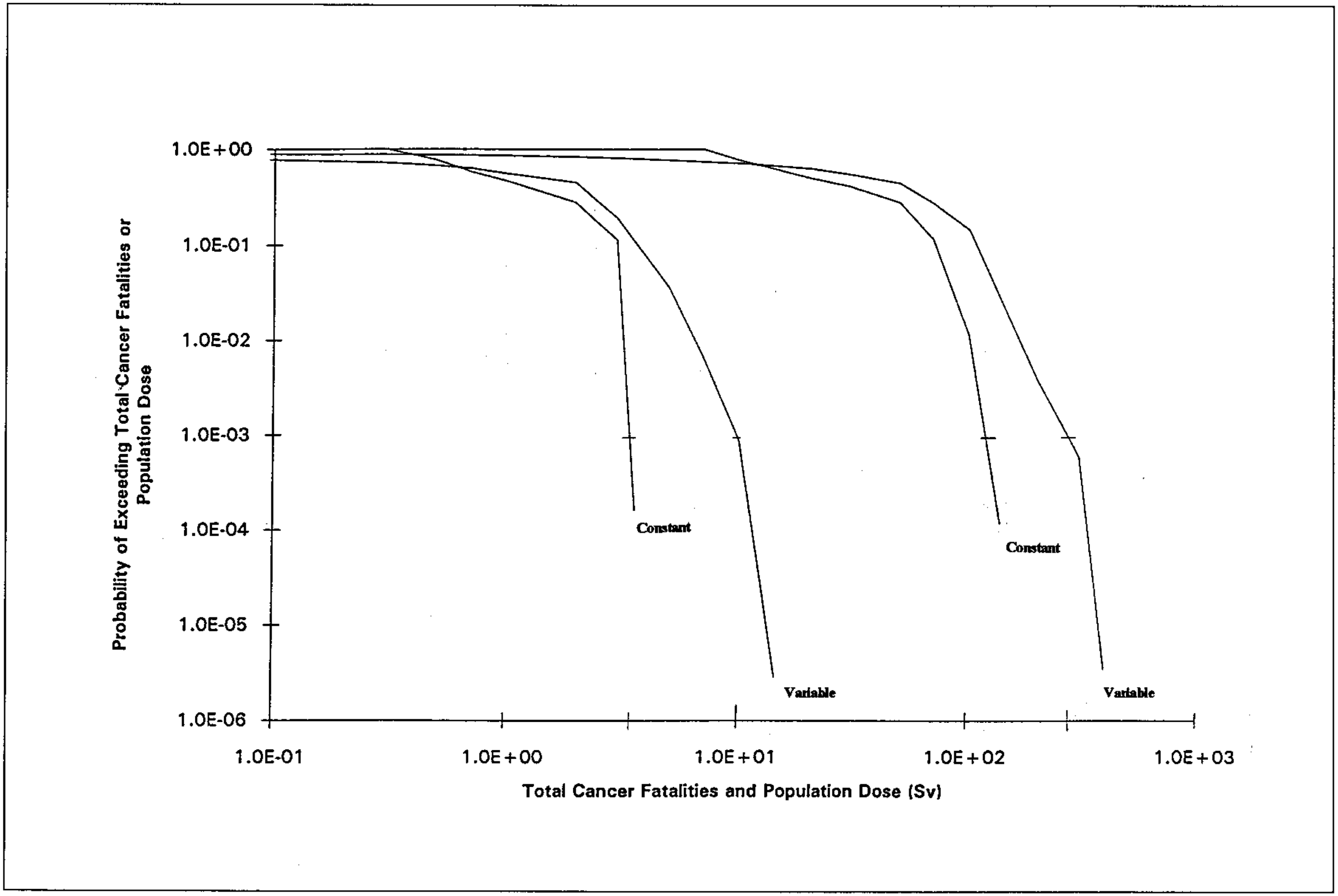

Figure D-59 Effective Dose Equivalent Whole Body Population Dose (Sv) (Dock) and Total Cancer Fatalities (Channel), 0-80 km (0-50 mi), Long Beach, Variable and Constant Meteorology, BR-2 Inventory, Severity Category 5 Releases

D.5.4.3.2 High-Temperature Sensitivity Calculations

As previously discussed, releases of radioactive material from spent nuclear fuel transportation casks are categorized by severity. Severity category 6, which results in the largest release, is assumed for the marine transportation portion of this EIS to be caused by a severe ship collision that results in damage to the transportation cask and a severe fire that engulfs the cask. Only around one in five severe ship fires reach temperatures above approximately 700°K or 800°F (see Attachment D5, Section 4). As discussed below, extremely high temperatures, above 900°K (1,160°F), result in phenomena that could significantly alter the release fraction for aluminum-based and TRIGA fuel (previous studies have not specifically addressed the impact of these phenomena). Therefore, the release fractions assumed for severity category 6 (Table D-21) are for temperatures of the spent nuclear fuel above 700°K (800°F) but below 900°K (1,160°F).

Section D.5.3.1 of this appendix developed probabilities of the more severe marine accidents. Table D-24 stated that the probability of a severity category 6 accident is 6×10^{-10}, or less than one chance in a billion per cask shipment. This very low probability is made even lower if the probability of the severe fire causing the spent nuclear fuel temperature to exceed 900°K (1,160°F) is considered. Appendix D Attachment D5 concludes that the probability of a severe ship fire exceeding spent nuclear fuel temperatures of 900°K (1,160°F) is 0.1. Multiplying the probability of a severity category 6 accident (6×10^{-10}) by the probability of a severe fire on the ship (0.1) results in the probability of a severity category 6 accident that includes a severe ship fire, 6×10^{-11}. This exceedingly small probability indicates that the occurrence of this condition is not a creditable accident. However, for completeness, an evaluation of the consequences of such an accident is presented below as a sensitivity calculation.

The review of the behavior of aluminum-uranium (Al-U) alloy and TRIGA fuels at temperatures above 900°K (1,160°F), presented in Attachment D5, found that at these temperatures Al-U fuels melt, and if exposed to air, TRIGA fuel burns. Table D5-2 (in Attachment D5) compares the release fractions estimated for these high-temperature scenarios to those used in the base case calculations. These data show the high-temperature events (the category 5B and 6B events) increase release from these fuels significantly.

Since both processes (melting and burning) are expected to produce fission product release fractions that are significantly larger than those used during base case calculations for severity category 6 accidents, sensitivity calculations were performed so that the consequences and risks associated with these larger releases could be compared to the consequences and risks of the base case results. Again the Elizabeth channel location was used to perform the sensitivity calculations. Three calculations were performed, two BR-2 aluminum-uranium alloy fuel calculations and one TRIGA fuel calculation. All of these calculations used the release fractions specified in Table D-39 for high-temperature scenarios. The first aluminum-uranium alloy fuel sensitivity calculation used severity category 5B and the second category 6B release fractions. The single TRIGA sensitivity calculation used category 6B release fractions. Calculations were not performed with any of the other sets of release fractions presented in Table D-39, because each of the other sets is smaller than the set used in the base case calculations that it would replace; and would thus yield smaller consequences and risks.

Table D-39 presents the results of these high-temperature sensitivity calculations and compares them to the base case results obtained using the same inventories but using the severity category 5 or 6 release fractions given in Table D-21. Table D-39 shows that, as expected, the larger severity category 5B and severity category 6B release fractions lead to consequences significantly larger than those obtained for the base case calculations that used severity category 5 and severity category 6 release fractions. Inspection of the table shows that the larger release fractions increase consequence estimates by factors of ten to 100.

Table D-39 High-Temperature Sensitivity Calculation Results

	BR-2				*TRIGA*	
Accident Severity Category	5	5B	6	6B	6	6B
Accident Probability	5×10^{-9}	5×10^{-10}	6×10^{-10}	6×10^{-11}	6×10^{-10}	6×10^{-11}
Peak Probability [0-1.6 km [0-1 mi)]	8.41×10^{-5}	7.65×10^{-5}	8.41×10^{-5}	7.03×10^{-5}	8.41×10^{-5}	2.17×10^{-4}
Peak Probability [0.80.5 km (0-50 mi)]	8.41×10^{-5}	1.16×10^{-5}	8.41×10^{-5}	1.45×10^{-5}	8.41×10^{-5}	1.45×10^{-5}
EDE Whole Body Population Dose (person-rem)						
0-1.6 km (0-1 mi)						
Mean	236	1,490	192	3,810	26.8	3,980
Peak	42,100	203,000	45,900	271,000	6,390	297,000
0-80.5 km (0-50 mi)						
Mean	6,930	68,400	6,770	639,000	937	298,000
Peak	133,000	1,450,000	145,000	14,400,000	20,200	6,390,000
Total Cancer Fatalities						
0-1.6 km (0-1 mi)						
Mean	0.098	0.622	0.0802	1.59	0.0112	1.66
Peak	17.5	84.5	19.1	113	2.66	123
0-80.5 km (0-50 mi)						
Mean	2.90	28.7	2.84	268	0.392	125
Peak	55.3	603	60.4	6,000	8.39	2,660
Impact Distances (km)						
Decontamination						
Mean	0.0	0.0156	0.0	0.302	0.0	0.0993
Peak	0.0	1.61	0.0	8.05	0.0	6.44
Cond. Peak Prob.	---	0.00969	---	0.00116	---	7.53×10^{-5}
Interdiction						
Mean	0.0	0.0156	0.0	0.302	0.0	0.0993
Peak	0.0	1.61	0.0	8.05	0.0	6.44
Cond. Peak Prob.	---	0.00969	---	0.00116	---	7.53×10^{-5}
Condemnation						
Mean	0.0	0.0	0.0	0.0292	0.0	0.00263
Peak	0.0	0.0	0.0	3.22	0.0	1.61
Cond. Peak Prob.	---	---	---	0.000648	---	0.00163
Population Dose Risk						
0-1.6 km (0-1 mi)						
Mean	1.2×10^{-6}	7.5×10^{-7}	1.2×10^{-7}	2.3×10^{-7}	1.6×10^{-8}	2.4×10^{-7}
Peak	1.8×10^{-8}	7.8×10^{-9}	2.3×10^{-9}	1.1×10^{-9}	3.2×10^{-10}	3.9×10^{-9}
0-80.5 km (0-50 mi)						
Mean	3.5×10^{-5}	3.4×10^{-6}	4.1×10^{-6}	3.8×10^{-5}	5.6×10^{-7}	1.8×10^{-5}
Peak	5.6×10^{-8}	8.4×10^{-9}	7.3×10^{-9}	1.3×10^{-8}	1.0×10^{-9}	5.5×10^{-9}
Cancer Fatality Risk						
0-1.6 km						
Mean	4.9×10^{-10}	4.4×10^{-10}	4.8×10^{-11}	9.5×10^{-11}	6.7×10^{-12}	1.0×10^{-10}
Peak	7.4×10^{-12}	3.2×10^{-12}	9.6×10^{-13}	4.8×10^{-13}	1.3×10^{-13}	1.6×10^{-12}
0-80.5 km						
Mean	1.5×10^{-7}	1.6×10^{-7}	1.7×10^{-9}	1.6×10^{-8}	2.4×10^{-10}	7.5×10^{-9}
Peak	2.3×10^{-11}	3.5×10^{-12}	3.0×10^{-12}	5.2×10^{-12}	4.2×10^{-13}	2.3×10^{-12}

However, because the probabilities of occurrence of these high-temperature release fractions (see Attachment D-5) for BR-2 aluminum uranium alloy fuel inventories are generally ten times smaller than those associated with the severity category 5 and severity category 6 accident categories, the risks associated with these larger releases are comparable to or smaller than those predicted for base case BR-2 calculations. For TRIGA fuel, severity category 6B release fractions are much larger than the severity category 6 release fractions. The probability of the severity category 6B release fractions is only ten times smaller than that of the severity category 6 release fractions. Therefore, the risks associated with a TRIGA fuel category 6B release are significantly larger than those obtained for the base case accident severity category 6 calculation. But, because the TRIGA inventory is substantially smaller than the BR-2 inventory, the TRIGA severity category 6B risks are still smaller than the risks obtained for base case calculations using the BR-2 inventory and the severity category 5 set of release fractions.

Other environmental impacts in addition to the public health consequences are presented in Table D-39. These impacts were determined as part of the MACCS calculations. MACCS calculated land impacts based on a habitability dose criterion and cost effectiveness of mitigative actions such as evacuation, temporary relocation, and land decontamination and interdiction. The habitability criterion is based on the need to take action to ensure that the dose to a person remains below 4 rem[1] over a 5-year period. MACCS code determines the mitigative actions in a predetermined sequence in order to select the least stringent action which will allow the habitability dose criterion to be satisfied. The order of actions is: 1) decontamination alone (minimum decontamination process, three levels of decontamination process can be specified), 2) maximum level of decontamination followed by an interdiction period, and 3) permanent interdiction (condemnation) of the land. The decontamination distance is that distance from the accident location that requires post-accident clean-up to ensure this dose level is not achieved. The land is usable, that is, people may live and work in the area, within a relatively short period after the accident. The interdiction distance is that distance from the accident that even after decontamination would require some time, typically seven years, before the land area would be useable. The condemnation distance characterizes the land area that even after decontamination would remain unusable for at least 30 years.

MACCS code calculates both the affected population in the urban areas and the affected farmlands in the rural areas. The affected distances, (i.e., decontamination, interdiction, and condemnation distances), in the rural areas are generally larger than those of the urban area. Since one of the principal uses of rural land is agricultural, the consumption of contaminated food produced in these areas would result in larger doses to some members of the public.

Table D-39 provides the land impact distances for an accident that occurs in the Port of Elizabeth for the most severe accident severity categories of both the base case calculations (category 5 and 6 for the BR-2 fuel and category 6 for the TRIGA fuel) and for the most severe of the high temperature accident scenarios (categories 5B and 6B for BR-2 fuel and category 6B for the TRIGA fuel). Since the ports are located primarily in urban areas, the impact distances presented are those based on the urban (population) impact calculations. For the base case accident scenarios, MACCS predicted no impact on the usability of the land. However, when temperatures reaching the melting point of the aluminum based fuel and the combustion temperature of the TRIGA fuel are realized, some land-use impacts are calculated. All mean impact distances are well under 1 km (0.6 mi), with the largest distance being approximately 300 m

1 *This arises from 2 rem in first year and 0.5 rem per year for the years 2 to 5. This criterion is consistent with the Environmental Protection Agency's long-term objectives of the Protective Action Guide, (Section 4.2.1 of "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA 1991).*

(1000 ft). The peak values quoted in Table D-39 represent the worst possible consequences, driven by meteorological conditions that create the maximum potential damage. The occurrences of these meteorological conditions are of low probabilities which are ranging from approximately one-in-one hundred to less than one-in-ten thousand.

In addition to the Port of Elizabeth, the land impact analysis was performed for several of the candidate ports, including Concord NWS, CA; Galveston, TX; MOTSU, NC; and Tacoma, WA. For these four ports, the mean values for the land impacts resulting from the category 6B accidents, the most severe of all accident categories, were of the same order of magnitude as, and slightly smaller than, the results presented in Table D-39 for the Port of Elizabeth.

D.5.4.3.3 Other Sensitivity Calculations

In addition to the two sensitivity calculations discussed above, sensitivity calculations were also performed that examined the effect on consequences of (1) plume buoyancy, (2) the size of the set of nuclides used to specify inventories, (3) Modal Study release fractions, (4) corrosion deposits release, and (5) work force population. Table D-40 summarizes the calculations performed. For all of these calculations, the reference calculation was the base case Elizabeth dock or channel calculation that used the BR-2 inventory, severity category 5 release fractions, and variable meteorology recorded at the New York City National Weather Service station. Work force sensitivity calculations used the Elizabeth dock population distribution. All of the other sensitivity calculations used the Elizabeth channel population distribution. Table D-41 presents mean and peak population doses and cancer fatalities for two distance ranges, 0-1.6 km and 0-80.5 km, (0-1 and 0-50 mi) for all of the "other" sensitivity calculations, and also for the reference Elizabeth base case calculations to which sensitivity calculation results should be compared.

D.5.4.3.3.1 Plume Buoyancy

As Table D-21 showed, a severity category 5 release scenario results from a collision and a severe fire. Thus, the first sensitivity calculation performed examined the effect of plume buoyancy (i.e, of plume rise) on accident consequences. This was done by repeating the Elizabeth channel reference calculation setting the sensible heat content of the release to zero. This change produces a cold plume that is not subject to plume rise and thus is not lofted over the population located close to the release point (the accident location). The results of this sensitivity calculation are presented in Table D-41.

Table D-41 shows that changing the reference Elizabeth channel calculation to a cold release not subject to plume rise causes mean and peak population doses and cancer fatalities to increase somewhat for the 0-80.5 km (0-50 mi) distance range and substantially for the 0-1.6 km (0-1 mi) distance range. For the 0-80.5 km (0-50 mi) distance range, mean population dose and cancer fatalities both increase by a factor of 2.4, and peak population dose and cancer fatalities increase by a factor of 1.1. For the 0-1.6 km (0-1 mi) distance range, mean population dose and cancer fatalities both increase by a factor of 17, and peak population dose and cancer fatalities both increase by a factor of 2.7. Thus, if engulfing fires increase release magnitudes, consequence magnitudes will not increase proportionately because the fire will produce a hot plume that will be lofted over nearby populations decreasing radiation exposures and thus health effects among those populations. It should be mentioned that the releases assumed here (category 5) are not considered possible *without* the fire. This calculation was done to show the sensitivity of the results to the presence of a fire.

Table D-40 Other Sensitivity Calculations

Run No.	Meteorology[a]		Nuclides[b]		Release Fractions[c]			Heat[d]		Shielding[e]	
	Variable	Constant	MACCS	EIS	5	MS/nM5	MS/M5	H	C	N	C
BC	x			x	x			x		x	
Buoyancy Calculations											
1a.	x			x	x				x	x	
Nuclide Sensitivity Calculations											
2a.	x		x		x			x			x
2b.	x		x		x				x		x
Modal Study Release Fraction Calculations											
3a.	x			x		x		x		x	
3b.	x			x			x	x		x	
Corrosion Products Calculations											
4a.[f]	x			x	EA3				x	x	
4b.[g]	x			x	x			x		x	
Work Force Calculations											
5a.	x			x	x			x		x	
5b.	x			x	x				x	x	
5c.	x			x	x				x		x
5d.[h]	x			x	x				x	x	
5e.[h]	x			x	x				x		x
5f.[i]	x			x	x				x	x	

[a]*Meteorology: Variable = hourly National Weather Service data, Constant = Joint Frequency Data.*

[b]*Nuclides: MACCS = 22 MACCS nuclides, EIS = 34 EIS nuclides.*

[c]*Release Fractions: 5 = severity category 5 release fractions; MS/nM5 = release fractions for nonmetallic (TRIGA) spent nuclear fuel for Modal study cask response region roughly corresponding to severity category 5; MS/M5 = release fraction for metallic (aluminum-based) spent nuclear fuel for Modal study cask response regions roughly corresponding to severity category 5.*

[d]*Heat: H = hot plume, C = cold plume.*

[e]*Shielding: N = normal shielding factors; C = sheltering shielding factors from 0-8 km (0-5 mi) for one day and normal shielding factors at all other times and distances.*

[f]*Only Corrosion Products released*

[g]*With Corrosion Products release added to the reference release.*

[h]*With puff and tail*

[i]*With puff and tail, and evacuation from 0-1.6 km (0-1 mi.)*

D.5.4.3.3.2 Size of Nuclide Set

Table D-25 presented the three inventories used in the base case analyses. Each inventory contains 34 radionuclides. The default set of radionuclides used by MACCS does not contain dose conversion factors for 13 of these 34 radionuclides. These 13 radionuclides are hydrogen-3, tin-123, antimony-125, tellurium-125m, promethium-147, promethium-148m, europium-154, europium-155m, uranium-234, uranium-235, uranium-238, americium-242m, and americium-243. *Chronic* health effect dose conversion factors for all 13 of these radionuclides were available (DOE, 1988a; DOE, 1988b) and were added to the MACCS dose conversion factor library for this study. However, because generally accepted *acute* health effect dose conversion factors were not available, all calculations performed for this study were run not including acute health effects for these 13 radionuclides.

Table D-41 Sensitivity Study Results, Elizabeth Dock and Channel, Inventory BR-2, Severity Category 5

Run	EDE Whole Body Population Dose (person-rem)				Total Cancer Fatalities			
	0-1.6 km (0-1 mi)		0-80.5 km (0-50 mi)		0-1.6 km (0-1 mi)		0-80.5 km (0-50 mi)	
	Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak
Base Case (Channel)	236	42,100	6,930	133,000	0.099	17.5	2.90	55.3
Buoyancy								
1	4,200	114,000	16,900	151,000	1.75	47.6	7.07	62.9
Nuclide Sensitivity								
2a	236	42,100	6,930	133,000	0.0985	17.5	2.90	55.3
2b	4,200	114,000	16,900	151,000	1.75	47.6	7.07	62.9
Modal Study Release Fraction								
3a	53.7	9,540	1,570	30,100	0.0224	3.98	0.661	12.6
3b	0.3	47.7	7.9	151	0.000112	0.0199	0.00331	0.0628
Corrosion Products Calculations								
4a	739	20,100	2,950	26,600	0.319	8.70	1.27	11.5
4b	278	49,400	8,120	156,000	0.116	20.7	3.42	65.4
Base Case (Dock)	71.3	13,300	6,550	113,000	0.0298	5.56	2.75	47.2
Work Force								
5a	105	14,400	6,600	113,000	0.0438	6.02	2.77	47.2
5b	1,870	40,400	11,200	84,600	0.780	16.8	4.69	35.3
5c	1,860	40,300	11,200	84,500	0.778	16.8	4.68	35.3
5d	1,940	40,400	11,600	72,500	0.810	16.9	4.84	30.2
5e	1,940	40,400	11,500	72,500	0.808	16.8	4.83	30.2
5f	1,940	40,300	11,500	72,500	0.808	16.8	4.83	30.2

The effect of not including acute impacts for 13 of the radionuclides in the inventories was examined by two sensitivity calculations. For these calculations, the reference Elizabeth channel calculation was performed with and without the chronic effects of the 13 radionuclides for two situations, once assuming a hot release, and once assuming a cold release. Table D-41 shows that removing these 13 radionuclides from the BR-2 inventory had no significant impact on either mean or peak values of population dose or cancer fatalities over the distance ranges 0-1.6 km (0-1 mi) and 0-80.5 km (0-50 mi) for either calculation. The cold release results and the hot release peak results are identical to those obtained using all 34 radionuclides in the full BR-2 inventory. The hot release mean values obtained with the 13 radionuclides removed differ by no more than 5 percent from the results obtained using 34 radionuclides. Thus, the 13 radionuclides for which acute dose conversion factors were not available do not contribute significantly to chronic dose or health effects, which suggests that none should have a significant impact on acute health effects.

The relative contributions to radiation exposures of the nuclides in an inventory can be estimated by normalizing the ratio of each nuclide's curie amount and the run 2a value by the sum of those ratios. A run 2a value is the curie amount of the radionuclide that produces significant radiation doses (IAEA, 1961; IAEA, 1990). The RADSEL code was used to perform this calculation for the set of 34 nuclides in the inventories used in this study. The RADSEL calculation showed that only one radionuclide, promethium-147, in the set of 13 nuclides for which acute health effect dose conversion factors were lacking, contributes significantly to dose at the 99.9 percent level. More importantly, the calculation also showed that promethium-147 accounts for only 0.5 percent of the total dose produced by the full set of 34 radionuclides. Thus, the 21 nuclides in the inventories for which acute health effect conversion factors were available account for all significant contributions to dose. Therefore, not including acute health effects for 13 of the 34 radionuclides in the inventories used in this study is not believed to have had a significant impact on the estimation of acute health effects, especially since none of these nuclides contributes significantly to chronic dose or health effects and since no acute effects were observed at any level including peak results for any calculation performed during this study.

D.5.4.3.3.3 Modal Study Cask Response Regions Release Fractions

The Modal Study (Fischer et al., 1987) developed release fractions for truck and rail accidents involving transportation cask containing commercial spent nuclear fuel. DOE as part of the preparation of the Programmatic SNF&INEL EIS, developed representative release fractions for metallic (aluminum-based) and nonmetallic (TRIGA) fuel for each of the Modal Study's cask response regions (DOE, 1995). Although there is not a direct relationship between the accident classification used in this EIS for ship accidents and that developed in the Modal Study, attempts were made to establish a meaningful comparison based on the definition of accidents and their consequences. Based on the accident definitions, one can approximate the severity category 5 ship accidents to the Modal Study's cask response region resulting from a medium impact mechanical force with a medium intensity thermal load. Table D-42 provides the values of release fractions used in this EIS for severity category 5 accident and that used for metallic and nonmetallic fuel in the Programmatic SNF&INEL EIS for a similar accident category. For ease of comparison, the EIS release fractions that were used in all of the base case calculations performed for this study are repeated in this table.

Table D-42 Programmatic SNF&INEL EIS Release Fractions

Element Group	*Release Fraction*		
	EIS (Base Case Category 5)	*Programmatic SNF&INEL EIS*	
		Metallic	*Nonmetallic*
Krypton	0.1	0.39	0.39
Cesium	9.0×10^{-4}	1.0×10^{-6}	0.00020
Ruthenium	1.0×10^{-6}	2.4×10^{-7}	0.000048
Particulate	5.0×10^{-8}	1.0×10^{-8}	0.0000020

Source: DOE, 1995

Inspection of the table shows that, except for the krypton element group, the base case EIS release fraction values for severity category 5 are somewhat larger than the values for nonmetallic fuel and are quite a bit larger than the values for metallic fuel. Thus, as would be expected, Table D-41 shows that mean and peak population doses and cancer fatalities for the distance ranges 0-1.6 and 0-80.5 km (0-1 and 0-50 mi) obtained using EIS release fractions are about five times larger than those obtained using nonmetallic fuel release fractions, which in turn are about 200 times larger than those obtained using metallic fuel release fractions. Therefore, since severity category 5 largely determines risk, use of EIS release fractions is conservative even if metallic and nonmetallic release fractions better represent releases during ship collisions.

D.5.4.3.3.4 Corrosion Products Release

During the operation of power reactors, radioactive cobalt is formed by neutron activation of chemical deposits on the outer surfaces of fuel rods. Thus, during transportation accidents, release of these radioactive deposits, usually referred to as corrosion products, can be a significant contributor to the size of the accident source term.

Because corrosion products formation is usually not a problem for research reactors, radioactive cobalt is not present in the inventories used in this study, and the sets of source terms input to MACCS do not contain fractions for corrosion products release. The potential impact of corrosion products release on foreign research reactor spent nuclear fuel accident source terms was examined by performing two sensitivity calculations. For these calculations, after scaling to match the size of the BR-2 inventory used in this study, the cobalt-60 content of the spent nuclear fuel inventory for a DOE test reactor (DOE, 1995) was added to the BR-2 inventory that was used in these sensitivity calculations (cobalt-58 was ignored as it should largely have decayed away before the fuel is shipped). Then, two sensitivity calculations were performed. Both calculations added 360 Ci of cobalt-60 to the BR-2 inventory and both used a value of 0.012 for the release fraction for the corrosion products chemical element group, as had been done in earlier studies. The first calculation examined the consequences of an accident that releases only corrosion products. Because corrosion products are not volatile, this release was assumed to be cold, that is driven by mechanical forces generated by the ship collision. The second calculation added the corrosion products release to the severity category 5 release used in the reference calculation. Because this release postulates a severe engulfing fire, the second calculation assumed that the release was hot.

Table D-41 shows that the first calculation, the cold release that contained only corrosion products (run 4a), leads to consequences that differ from those produced by the reference calculation as follows: for the 0-1.6 km (0-1 mi) distance range, mean values of population dose and cancer fatalities are about three times larger and peak values about two times smaller; for the 0-80.5 km (0-50 mi) distance range, mean and peak values for these two consequences are both smaller than the reference calculation results by factors of about 2.5 and 5 respectively. Mean and peak results for the 0-80.5 km (0-50 mi) distance range and peak results for the 0-1.6 km (0-1 mi) range are smaller because the curie content of the corrosion products release is smaller than the total curie content of the release used in the reference calculation (the release produced by severity category 5 release fractions and the BR-2 inventory). Mean results for the 0-1.6 km (0-1 mi) distance range are larger because the release is cold and therefore not lofted over nearby populations. Table D-41 also shows that adding the corrosion products release to the reference calculation (run 4b) increases consequence predictions only slightly (by about 20 percent), as would be expected given the small curie content of the corrosion products release compared to the reference release.

D.5.4.3.3.5 Work Force Population

Approximately 7,000 people work in Port Elizabeth in Newark, NJ. Thus, at least for accidents that occur during the workweek, these workers could be exposed to radiation as a result of a ship collision that involves a ship carrying foreign research reactor spent nuclear fuel. Inspection of maps showed that these workers should be added to the residential populations in the first distance intervals of the north sector of the Newark dock population distribution. Since the division of workers between these two distance intervals was not known, 3,500 workers were added to each interval for these sensitivity calculations.

Work force sensitivity calculations were performed first assuming, as was done for the reference calculation, a hot release, the BR-2 inventory, and severity category 5 release fractions. Then, this calculation was repeated two times assuming a cold release. The first of these two cold release calculations used the same shielding factors that had been used in the reference calculation. For the second cold release calculation, larger shielding factors were used during the first 24 hours after the accident over the distance range 0-8 km (0-5 mi) because the commercial buildings near the port are likely to provide better shielding than is provided by the mix of buildings located within 80.5 km (50 mi) of the port. Next, these two cold release calculations were repeated assuming that the release consists of a puff caused by the collision impact and a tail caused by the ensuing fire. Severity category 4 release fractions were used for the puff, and the release fractions for the tail were obtained by subtracting the severity category 4 release fractions from the severity category 5 release fractions. The puff was released when the collision occurred and lasted for 10 minutes; the tail was released one hour later and had a one hour release duration. Finally, the puff and tail calculation that did not use increased shielding factor values was repeated assuming that an evacuation would be called for should a severe accident lead to a fire that engulfed a radioactive material transportation cask, that the evacuation would begin about one hour after the accident took place (i.e., at about the time the tail release begins), and that the average evacuation speed would be slow because of city congestion.

Inspection of Table D-41 shows that, when a hot release is assumed (run 5a), adding a work force population increases mean population dose and cancer fatalities by less than a factor of 2 in the 0-1.6 km (0-1 mi) distance range, but has little effect on peak values in this distance range or on either mean or peak values in the 0-80.5 km (0-50 mi) distance range. When the release is cold (run 5b), 0-1.6 km (0-1 mi) mean population doses and cancer fatalities are increased by factors of about 26 and 2 respectively, and peak doses and cancer fatalities are increased by factors of about 3. For the 0-80.5 km (0-50 mi) distance range mean results are increased by factors of about 2 and peak results actually decrease by a factor of about 0.7. Moreover, these results are little changed by using increased shielding factors for commercial buildings, by assuming a puff and tail release, or by assuming a slow delayed evacuation.

The insensitivity to short-term shielding factor values, to release timing, and to evacuation is easy to understand when one remembers that population dose and cancer fatalities in these calculations are determined almost entirely by long-term groundshine exposures, which are of course little influenced by variation of any of these three short-term effects. Thus, as was shown above, elimination of lofting by assuming a cold release increases consequences, especially those that occur at short distances, but little else has much effect because only recovery actions (decontamination, temporary interdiction, condemnation) not examined by these sensitivity calculations can significantly affect long-term groundshine dose.

D.5.5 Port Accident Risk

The port accident risk analysis combines the results of the analysis of the frequency of ship accidents in the port area with the results of the consequence analysis of each of these accidents. Each of the accident severity categories contributes to the overall risk of accidents in the port. The total risk is the sum of the risk for each severity category. The specific methodology used to evaluate port accident risks and the results of that analysis are presented in this section.

The port accident risk analysis was performed based on 721 individual shipments of foreign research reactor spent nuclear fuel. Unlike the incident-free analyses, where the shipment of two or more casks on the same vessel results in an increase in the worker risk, the number of casks shipped on a single vessel does not affect the results of the analysis. The larger the number of casks on a single vessel, the fewer the number of shipments required to ship all 721 casks. Accident data is generated on a per transit basis. Assuming a single cask per shipment maximizes the number of shipments and maximizes the probability of an accident involving a ship carrying foreign research reactor spent nuclear fuel. If it is assumed that an accident that results in damage to a foreign research reactor spent nuclear fuel cask results in damage to all of the casks on a single vessel, the risks from the shipment of multiple casks on a single vessel would be identical to the risks associated with the shipment of the same number of casks individually. From the analysis performed in Appendix D Attachment D4, it is apparent that the probability of damage to all casks given that one is damaged in an accident is less than one. Therefore, performing the port accident risk analysis assuming that one cask is shipped per voyage results in an estimate of risk that is maximized for number of transportation casks shipped per voyage.

The accident risks have been evaluated for 13 ports: Elizabeth, NJ; the Hampton Roads, VA, ports of Portsmouth, Norfolk, and Newport News (using Portsmouth as the representative port); MOTSU, NC; Charleston, SC; Philadelphia. PA; Long Beach, CA; Savannah, GA; Galveston, TX; Concord NWS, CA; Tacoma, WA; Wilmington, NC; Jacksonville, FL; and Portland, OR. Although high population density ports do not meet the port selection screening criteria, the three high population ports of Elizabeth, Long Beach, and Philadelphia were included in the analysis for two purposes. First, it is possible that the shipments of foreign research reactor spent nuclear fuel could be made on vessels that make intermediate port calls, which could include these high population ports. Additionally, by evaluating these high population ports as ports of entry it was possible to estimate the maximum port accident risks resulting from the shipment of foreign research reactor spent nuclear fuel into the United States.

As discussed in the port accident consequence analysis (Section D.5.4), the accident analysis has evaluated the impact of accidents at two locations within each of the ports considered in the risk analysis. The two locations represent the possibility of: (1) an accident involving the ship transporting the foreign research reactor spent nuclear fuel while at the dock and (2) an accident at some point in the approach to the dock. Two locations were selected to address the possibility that the terminal (pier at which the cargo vessel is docked) may not be the location within the port that would yield the highest consequences for an accident. The key consideration is that in approaching the terminal, at some ports, the cargo vessel would pass through areas with a higher nearby population than the area around the terminal. To ensure that the accident consequence analysis did not underestimate the potential consequences, this second accident location was selected. It was selected by identifying the point in the approach to the terminal which had characteristics most likely to result in consequences representative of the largest consequences associated with an accident within the port facility. This generally meant a location near a population center. Accident locations were identified earlier in Table D-28.

Because two locations were selected for the accident analysis in each port, the total risk associated with a port call at the port of entry is the sum of the risks at these two locations. Accidents may occur either at the terminal (dock) or in the channel as the vessel approaches the dock This risk can be expressed as:

$$R_{PE} = \sum \left(M_D P_D + M_C P_C \right)$$

where:

R_{PE}=Risks from accidents in the port of entry,

M_D=Magnitude of the consequences for a severity category 4, 5, 6 accident at the dock,

P_D=Probability of an accident of severity category 4, 5, 6 at the dock,

M_C=Magnitude of the consequences for an accident in the approach to the dock (in the channel), and

P_C=Probability of an accident of severity category 4, 5, 6 in the approach to the dock (in the channel).

One of the assumptions made in the port risk analysis is that the vessel carrying the foreign research reactor spent nuclear fuel may make intermediate port calls at up to two different ports before arriving at the port of entry. In the event that these intermediate port calls are made, the risks associated with each of these port calls can be expressed as follows:

$$R_{IP} = \sum \left(M_D P_D + 2\ M_C P_C \right)$$

where R_{IP} is the risk from an accident in one of the intermediate ports of call. All other parameters have the same definitions as in the equation defining R_{PE}. The risks associated with accidents in the channel of the port is considered twice for the intermediate ports because the vessel must enter the harbor and approach the dock and, with the foreign research reactor spent nuclear fuel still on board, must depart the harbor. The accident frequency data is derived as a per transit frequency. For this risk analysis the approach to the dock has been considered to be part of one transit, the departure as part of a second transit.

From Section D.5.3.1.7, the probabilities per transit for the three accident severity categories evaluated are provided in Table D-43. These accident frequencies were used to develop the per transit probabilities for the accidents at the dock and in the channel for each of the intermediate ports and the ports of entry for the foreign research reactor spent nuclear fuel. The port accident data collected was not detailed enough to determine the percentage of accidents that occurred at the dock versus the percentage that occurred in the channel. For the purposes of this analysis, it was assumed that the accidents were evenly distributed between the dock and the approach to the dock. Table D-43 presents the per transit probabilities used in the port accident analysis for accidents at the dock and in the channel.

Table D-43 Port Accident Probabilities

Accident Severity Category	P	P_d	P_c
4	0.000006	0.000003	0.000003
5	0.000000005	0.0000000027	0.0000000027
6	0.0000000006	0.0000000003	0.0000000003

Accident consequences (mean results) for each of the accident severity categories are reproduced in Tables D-44 and D-45, in terms of total population dose and LCF, respectively. The consequences vary depending on the type of fuel involved in the accident, the port at which the accident occurs, the severity category, and the location of the accident within the port environs. The largest differences are between the different release categories and is the result of the smaller release fractions for a severity category 4 accident than for the severity category 5 and 6 accidents. Between the different ports assessed in the analysis, the consequences vary by a factor of approximately 30 [i.e., the consequences of an accident in Elizabeth (the location of the highest consequences) are approximately 30 times greater than the consequences of the same accident at MOTSU (the location with the lowest consequences)].

Using the equations presented previously in this section, the probability and consequence data were combined to generate the risk data presented in Table D-46. This table presents data on a per shipment basis and for the shipment of all 721 foreign research reactor spent nuclear fuel casks. Data is presented for shipments that are made with no intermediate port stops (identified as direct shipments in the table) and for shipments that are made with intermediate port stops. The direct shipments are quantified using the relationship developed for R_{PE}. For example, the risks in terms of person-rem associated with a single direct shipment consisting of a single cask of BR-2 fuel into the port of Elizabeth are the sum of the severity category 4 risks, severity category 5 risks, and severity category 6 risks associated with accidents at the Elizabeth dock (0.00000069, 0.000018, 0.0000020) and in the approach to the port of Elizabeth (0.0000011, 0.000019, 0.0000020), which is 0.000042 as shown in the table.

In developing the risk estimates for shipments that pass through intermediate ports, several combinations of intermediate ports were considered for each ultimate port of entry. The ports selected for use in this analysis represent the range of populations found in ports around the United States. As stated previously; Elizabeth, Philadelphia, and Long Beach are considered high population ports; Portland, Jacksonville, Tacoma, Concord NWS, and the Hampton Roads ports are considered to be intermediate population ports; and Charleston, Savannah, Wilmington, Galveston, and MOTSU are considered low population ports. Each possible combination of populations was considered for the intermediate ports. The risks associated

Table D-44 Port Accident Analysis—Total Effective Dose Equivalent Population Dose (Person-Rem)

Location	BR-2 Spent Nuclear Fuel Severity Category			RHF Spent Nuclear Fuel Severity Category			TRIGA Spent Nuclear Fuel Severity Category		
	4	5	6	4	5	6	4	5	6
Elizabeth (D)[1]	0.23	6600	6500	0.093	2600	2600	0.028	910	900
Elizabeth (C)[2]	0.38	6900	6800	0.15	2700	2700	0.045	960	940
Long Beach (D)[1]	0.21	4700	4800	0.085	1900	1900	0.025	650	660
Long Beach (C)[2]	0.081	4300	4400	0.032	1700	1700	0.0097	590	610
Philadelphia (D)[1]	0.18	2800	2800	0.071	1100	1100	0.021	380	380
Philadelphia (C)[2]	0.085	2700	2800	0.034	1100	1100	0.010	370	380
Portland (D)[1]	0.077	1200	1200	0.031	450	450	0.0093	160	160
Portland (C)[2]	0.053	1100	1200	0.021	430	440	0.0065	150	150
Norfolk (D)[1]	0.055	850	830	0.022	330	320	0.0067	110	110
Norfolk (C)[2]	0.030	670	660	0.012	250	250	0.0037	87	87
Charleston Wando Terminal (D)[1]	0.024	420	410	0.0096	150	150	0.003	53	53
Charleston NWS (D)[1]	0.016	480	480	0.0066	180	180	0.0021	61	61
Charleston (C)[2]	0.038	420	420	0.015	160	160	0.0046	54	54
Tacoma (D)[1]	0.056	1,700	1,800	0.022	670	700	0.0068	230	250
Tacoma (C)[2]	0.039	1,400	1,500	0.016	550	570	0.0048	190	200
Concord NWS (D)[1]	0.044	2,100	2,200	0.018	800	850	0.0054	280	300
Concord NWS (C)[2]	0.094	3,300	3,400	0.038	1,300	1,300	0.011	450	460
Jacksonville (D)[1]	0.028	680	680	0.011	260	250	0.0035	88	87
Jacksonville (C)[2]	0.026	530	550	0.010	200	200	0.0032	69	70
Savannah (D)[1]	0.056	490	500	0.022	180	180	0.0068	62	63
Savannah (C)[2]	0.013	380	390	0.005	140	140	0.0018	47	49
Wilmington (D)[1]	0.038	480	500	0.015	180	190	0.0047	62	64
Wilmington (C)[2]	0.0097	210	220	0.0038	75	80	0.0012	26	27
Galveston (D)[1]	0.073	1,400	1,600	0.029	550	600	0.0089	190	210
Galveston (C)[2]	0.032	1,400	1,600	0.013	540	590	0.0041	190	200
MOTSU (D)[1]	0.0073	210	220	0.0029	75	80	0.0010	25	27
MOTSU (C)[2]	0.0097	210	220	0.0038	75	80	0.0012	26	27

[1]*Accident is at the Dock*

[2]*Accident is in the Channel, the approach to the dock*

with a shipment that passed through two U.S. ports before arriving at the port of entry for the foreign research reactor spent nuclear fuel were calculated using the relationships for R_{PE} and R_{IP}. The risks were calculated for each intermediate port stop and added to the risks associated with operations within the port of entry, i.e., the risks associated with a direct shipment.

The per shipment data was used to calculate the risks associated with the basic implementation of Management Alternative 1 of proposed action. The values shown in the two rightmost columns of Table D-46 represent the risks associated with the shipment of all of the foreign research reactor spent nuclear fuel through a single port of entry via the same intermediate ports. Using the shipments through Elizabeth as an example, the value given for the program risks for the shipment of the foreign research reactor spent nuclear fuel through one intermediate and one low population port (0.027 person-rem or 0.000011 LCF) assumes that all 721 foreign research reactor spent nuclear fuel casks are shipped through these same three ports. The number of shipments of each type of fuel (473 BR-2, 86 RHF, and 162 TRIGA) were incorporated into the development of the risks.

Table D-45 Port Accident Analysis—Accident Consequences (LCF)

Location	BR-2 Spent Nuclear Fuel			RHF Spent Nuclear Fuel			TRIGA Spent Nuclear Fuel		
	Severity Category			Severity Category			Severity Category		
	4	5	6	4	5	6	4	5	6
Elizabeth (D)[1]	0.00010	2.8	2.7	0.000041	1.1	1.1	0.000011	0.38	0.38
Elizabeth (C)[2]	0.00016	2.9	2.8	0.000066	1.1	1.1	0.000018	0.40	0.39
Long Beach (D)[1]	0.000093	2.0	2.0	0.000038	0.78	0.80	0.000010	0.27	0.28
Long Beach (C)[2]	0.000035	1.8	1.9	0.000014	0.71	0.73	0.0000040	0.25	0.26
Philadelphia (D)[1]	0.000078	1.2	1.2	0.000031	0.47	0.46	0.0000087	0.16	0.16
Philadelphia (C)[2]	0.000037	1.2	1.2	0.000015	0.45	0.47	0.0000042	0.16	0.16
Portland (D)[1]	0.000034	0.52	0.53	0.000014	0.20	0.20	0.0000039	0.068	0.069
Portland (C)[2]	0.000023	0.50	0.51	0.0000093	0.19	0.19	0.0000027	0.065	0.067
Norfolk (D)[1]	0.000024	0.38	0.37	0.0000097	0.14	0.14	0.0000028	0.049	0.048
Norfolk (C)[2]	0.000013	0.30	0.30	0.0000053	0.11	0.11	0.0000015	0.039	0.039
Charleston Wando Terminal (D)[1]	0.000011	0.19	0.19	0.0000042	0.070	0.070	0.0000012	0.024	0.024
Charleston NWS (D)[1]	0.0000068	0.22	0.22	0.0000027	0.080	0.080	0.00000084	0.028	0.028
Charleston(C)[2]	0.000017	0.19	0.19	0.0000067	0.070	0.071	0.0000019	0.024	0.024
Tacoma (D)[1]	0.000024	0.75	0.80	0.0000097	0.29	0.30	0.0000028	0.10	0.11
Tacoma (C)[2]	0.000017	0.63	0.66	0.0000068	0.24	0.25	0.0000020	0.083	0.087
Concord NWS (D)[1]	0.000019	0.90	0.96	0.0000076	0.34	0.37	0.0000022	0.12	0.13
Concord NWS (C)[2]	0.000041	1.4	1.5	0.000017	0.55	0.56	0.0000046	0.19	0.20
Jacksonville (D)[1]	0.000012	0.31	0.31	0.0000049	0.11	0.11	0.0000015	0.039	0.039
Jacksonville (C)[2]	0.000011	0.24	0.25	0.0000045	0.090	0.092	0.0000013	0.031	0.032
Savannah (D)[1]	0.000025	0.23	0.23	0.0000099	0.083	0.085	0.0000028	0.028	0.029
Savannah (C)[2]	0.0000059	0.18	0.19	0.0000023	0.065	0.067	0.00000074	0.022	0.023
Wilmington (D)[1]	0.000017	0.22	0.23	0.0000067	0.081	0.084	0.0000019	0.028	0.029
Wilmington (C)[2]	0.0000042	0.098	0.10	0.0000017	0.035	0.037	0.0000005	0.012	0.013
Galveston (D)[1]	0.000032	0.64	0.70	0.000013	0.24	0.27	0.0000037	0.084	0.092
Galveston (C)[2]	0.000014	0.63	0.69	0.0000056	0.24	0.26	0.0000017	0.082	0.090
MOTSU (D)[1]	0.0000032	0.099	0.11	0.0000013	0.035	0.038	0.00000041	0.012	0.013
MOTSU (C)[2]	0.0000042	0.098	0.10	0.0000017	0.035	0.037	0.00000052	0.012	0.013

[1] *Accident is at the Dock*

[2] *Accident is in the Channel, the approach to the dock*

Table D-46 Summary of Latent Cancer Fatalities and Population Exposure Risk—Per Shipment and for the Entire Program (Basic Implementation)

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
Elizabeth via:								
Two High Population Ports	0.00013	0.000052	0.000018	0.000000056	0.000000022	0.0000000075	0.070	0.000029
One High and One Intermediate Population Port	0.00011	0.000044	0.000016	0.000000048	0.000000019	0.0000000065	0.060	0.000025
One High and One Low Population Port	0.00011	0.000043	0.000015	0.000000045	0.000000018	0.0000000062	0.057	0.000024

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
Two Intermediate Population Ports	0.000056	0.000022	0.0000076	0.000000024	0.0000000093	0.0000000032	0.030	0.000013
One Intermediate and One Low Population Port	0.000051	0.000020	0.0000070	0.000000022	0.0000000085	0.0000000029	0.027	0.000011
Two Low Population Ports	0.000046	0.000018	0.0000063	0.000000020	0.0000000077	0.0000000026	0.024	0.000010
Direct	0.000042	0.000017	0.0000058	0.000000018	0.0000000070	0.0000000024	0.022	0.0000094
Long Beach via:								
Two High Population Ports	0.000011	0.000044	0.000015	0.000000047	0.000000018	0.0000000064	0.058	0.000025
One High and One Intermediate Population Port	0.000080	0.000032	0.0000011	0.000000034	0.000000013	0.0000000043	0.042	0.000018
One High and One Low Population Port	0.000071	0.000028	0.0000097	0.000000030	0.0000000012	0.0000000041	0.038	0.000016
Two Intermediate Population Ports	0.000050	0.000019	0.0000067	0.000000021	0.0000000083	0.0000000022	0.026	0.000011
One Intermediate and One Low Population Port	0.000041	0.000016	0.0000055	0.000000018	0.0000000068	0.0000000020	0.022	0.0000092
Two Low Population Ports	0.000032	0.0000013	0.0000043	0.000000014	0.0000000053	0.0000000018	0.017	0.0000072
Direct	0.000028	0.0000011	0.0000038	0.000000012	0.0000000046	0.0000000016	0.015	0.0000062
Philadelphia via:								
Two High Population Ports	0.00011	0.000042	0.000015	0.000000045	0.000000018	0.0000000061	0.057	0.000024
One High and One Intermediate Population Port	0.000088	0.000035	0.000012	0.000000037	0.000000015	0.0000000050	0.047	0.000020
One High and One Low Population Port	0.000083	0.000033	0.000011	0.000000035	0.000000014	0.0000000048	0.044	0.000019
Two Intermediate Population Ports	0.000031	0.000012	0.0000041	0.000000014	0.0000000052	0.0000000018	0.016	0.0000072

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
One Intermediate and One Low Population Port	0.000026	0.000010	0.0000035	0.000000011	0.0000000044	0.0000000015	0.014	0.0000061
Two Low Population Ports	0.000021	0.0000083	0.0000028	0.0000000093	0.0000000036	0.0000000012	0.011	0.0000049
Direct	0.000017	0.0000069	0.0000023	0.0000000075	0.0000000029	0.0000000099	0.0092	0.0000040
Portland via:								
Two High Population Ports	0.000090	0.000035	0.000012	0.000000038	0.000000015	0.0000000050	0.047	0.000020
One High and One Intermediate Population Port	0.000059	0.000023	0.0000080	0.000000025	0.0000000099	0.0000000029	0.031	0.000013
One High and One Low Population Port	0.000050	0.000020	0.0000068	0.000000022	0.0000000084	0.0000000027	0.027	0.000011
Two Intermediate Population Ports	0.000029	0.000011	0.0000039	0.000000013	0.0000000049	0.00000000088	0.015	0.0000066
One Intermediate and One Low Population Port	0.000020	0.0000077	0.0000027	0.0000000090	0.0000000034	0.00000000068	0.011	0.0000048
Two Low Population Ports	0.000011	0.0000042	0.0000015	0.0000000051	0.0000000019	0.00000000049	0.0059	0.0000026
Direct	0.0000073	0.0000028	0.00000098	0.0000000032	0.0000000012	0.00000000026	0.0039	0.0000017
Norfolk via:								
Two High Population Ports	0.000095	0.000037	0.000013	0.000000040	0.000000016	0.0000000054	0.050	0.000021
One High and One Intermediate Population Port	0.000076	0.000030	0.000010	0.000000032	0.000000013	0.0000000043	0.040	0.000017
One High and One Low Population Port	0.000071	0.000028	0.0000097	0.000000030	0.000000012	0.0000000040	0.037	0.000016
Two Intermediate Population Ports	0.000019	0.0000071	0.0000024	0.0000000083	0.0000000031	0.0000000011	0.0098	0.0000044
One Intermediate and One Low Population Port	0.000014	0.0000052	0.0000018	0.0000000061	0.0000000023	0.00000000078	0.0072	0.0000032
Two Low Population Ports	0.0000088	0.0000033	0.0000011	0.0000000040	0.0000000015	0.00000000050	0.0046	0.0000021

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
Direct	0.0000048	0.0000018	0.00000062	0.0000000021	0.0000000081	0.00000000028	0.0025	0.0000011
Charleston (Wando Terminal) via:								
Two High Population Ports	0.000092	0.000036	0.000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000074	0.000029	0.000010	0.000000031	0.000000012	0.0000000042	0.039	0.000016
One High and One Low Population Port	0.000069	0.000027	0.0000094	0.000000029	0.000000011	0.0000000039	0.036	0.000015
Two Intermediate Population Ports	0.000016	0.0000063	0.0000021	0.0000000074	0.0000000028	0.00000000095	0.0087	0.0000039
One Intermediate and One Low Population Port	0.000012	0.0000043	0.0000015	0.0000000052	0.0000000019	0.00000000066	0.0061	0.0000027
Two Low Population Ports	0.0000066	0.0000024	0.00000082	0.0000000031	0.0000000011	0.00000000038	0.0035	0.0000016
Direct	0.0000027	0.000001	0.00000034	0.0000000012	0.00000000045	0.00000000015	0.0014	0.00000064
Charleston NWS via:								
Two High Population Ports	0.000093	0.000033	0.000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000074	0.000029	0.000010	0.000000031	0.000000012	0.0000000042	0.039	0.000016
One High and One Low Population Port	0.000069	0.000027	0.0000094	0.000000029	0.000000011	0.0000000039	0.036	0.000015
Two Intermediate Population Ports	0.000017	0.0000063	0.0000022	0.0000000075	0.0000000028	0.00000000096	0.0084	0.0000039
One Intermediate and One Low Population Port	0.000012	0.0000044	0.0000015	0.0000000053	0.0000000020	0.00000000067	0.0058	0.0000028
Two Low Population Ports	0.0000068	0.0000025	0.00000084	0.0000000032	0.0000000011	0.00000000039	0.0032	0.0000017
Direct	0.0000028	0.0000011	0.00000036	0.0000000013	0.00000000048	0.00000000016	0.0011	0.00000068
MOTSU via:								
Two High Population Ports	0.000091	0.000036	0.000012	0.000000039	0.000000015	0.0000000052	0.048	0.000020

Port	Risks per Shipment: Population Exposure per Shipment (person-rem) BR-2	RHF	TRIGA	Risk per Shipment (LCF) BR-2	RHF	TRIGA	Program Risks: Expos. (person-rem)	Risk (LCF)
One High and One Intermediate Population Port	0.000072	0.000028	0.0000099	0.000000031	0.000000012	0.0000000041	0.038	0.000016
One High and One Low Population Port	0.000067	0.000026	0.0000092	0.0000000028	0.0000000011	0.0000000038	0.036	0.000015
Two Intermediate Population Ports	0.000015	0.0000057	0.0000019	0.0000000068	0.0000000025	0.00000000087	0.0080	0.0000036
One Intermediate and One Low Population Port	0.000010	0.0000038	0.0000013	0.0000000046	0.0000000017	0.00000000058	0.0054	0.0000024
Two Low Population Ports	0.0000053	0.0000019	0.00000064	0.0000000025	0.00000000088	0.0000000003	0.0028	0.0000013
Direct	0.0000013	0.00000047	0.00000016	0.00000000062	0.00000000022	0.000000000075	0.00069	0.00000032
Galveston via:								
Two High Population Ports	0.000099	0.000039	0.000013	0.000000042	0.000000016	0.0000000056	0.052	0.000022
One High and One Intermediate Population Port	0.000080	0.000031	0.000011	0.000000034	0.000000013	0.0000000046	0.042	0.000018
One High and One Low Population Port	0.000075	0.000029	0.0000010	0.000000032	0.0000000012	0.0000000043	0.040	0.000017
Two Intermediate Population Ports	0.000023	0.0000087	0.0000030	0.000000010	0.0000000038	0.0000000013	0.012	0.0000053
One Intermediate and One Low Population Port	0.000018	0.0000067	0.0000023	0.0000000080	0.000000003	0.000000001	0.0094	0.0000042
Two Low Population Ports	0.000013	0.0000048	0.0000017	0.0000000058	0.0000000022	0.00000000074	0.0068	0.0000031
Direct	0.0000090	0.0000034	0.0000012	0.0000000040	0.0000000015	0.00000000052	0.0047	0.0000021
Jacksonville via:								
Two High Population Ports	0.000094	0.000037	0.000013	0.000000040	0.000000016	0.0000000053	0.050	0.000021
One High and One Intermediate Population Port	0.000075	0.000029	0.00001	0.000000032	0.000000012	0.0000000043	0.040	0.000017

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
One High and One Low Population Port	0.000070	0.000027	0.0000096	0.000000029	0.000000012	0.0000000040	0.037	0.000016
Two Intermediate Population Ports	0.000018	0.0000067	0.0000023	0.0000000079	0.0000000030	0.0000000010	0.0093	0.0000041
One Intermediate and One Low Population Port	0.000013	0.0000048	0.0000016	0.0000000057	0.0000000021	0.00000000073	0.0067	0.000003
Two Low Population Ports	0.0000078	0.0000028	0.00000097	0.0000000036	0.0000000013	0.00000000045	0.0041	0.0000019
Direct	0.0000038	0.0000014	0.00000049	0.0000000017	0.00000000064	0.00000000022	0.0020	0.00000090
Savannah via:								
Two High Population Ports	0.000093	0.000037	0.000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000074	0.000029	0.00001	0.000000031	0.000000012	0.0000000042	0.039	0.000016
One High and One Low Population Port	0.000069	0.000027	0.0000094	0.000000029	0.000000011	0.0000000039	0.036	0.000015
Two Intermediate Population Ports	0.000017	0.0000063	0.0000021	0.0000000075	0.0000000028	0.00000000095	0.0088	0.0000039
One Intermediate and One Low Population Port	0.000012	0.0000044	0.0000015	0.0000000053	0.000000002	0.00000000067	0.0062	0.0000028
Two Low Population Ports	0.0000068	0.0000025	0.00000083	0.0000000032	0.0000000011	0.00000000039	0.0036	0.0000017
Direct	0.0000028	0.000001	0.00000035	0.0000000013	0.00000000048	0.00000000016	0.0015	0.00000069
Wilmington via:								
Two High Population Ports	0.000092	0.000036	0.000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000073	0.000029	0.00001	0.000000031	0.000000012	0.0000000042	0.039	0.000016
One High and One Low Population Port	0.000068	0.000027	0.0000094	0.000000029	0.000000011	0.0000000039	0.036	0.000015
Two Intermediate Population Ports	0.000016	0.0000061	0.0000021	0.0000000072	0.0000000027	0.00000000092	0.0084	0.0000038

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
One Intermediate and One Low Population Port	0.000011	0.0000042	0.0000014	0.0000000050	0.0000000019	0.00000000064	0.0058	0.0000026
Two Low Population Ports	0.0000062	0.0000022	0.00000076	0.0000000029	0.0000000010	0.00000000035	0.0032	0.0000015
Direct	0.0000022	0.00000082	0.00000028	0.0000000010	0.00000000037	0.00000000013	0.0012	0.00000053
Tacoma via:								
Two High Population Ports	0.000092	0.000036	0.0000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000062	0.000024	0.0000084	0.000000026	0.000000010	0.0000000032	0.033	0.000014
One High and One Low Population Port	0.000053	0.000021	0.0000072	0.000000023	0.0000000088	0.0000000031	0.028	0.000012
Two Intermediate Population Ports	0.000031	0.000012	0.0000042	0.000000014	0.0000000053	0.0000000012	0.017	0.0000072
One Intermediate and One Low Population Port	0.000023	0.0000086	0.0000030	0.000000010	0.0000000038	0.00000000099	0.012	0.0000053
Two Low Population Ports	0.000014	0.0000052	0.0000018	0.0000000061	0.0000000023	0.00000000079	0.0072	0.0000032
Direct	0.0000097	0.0000038	0.0000013	0.0000000043	0.0000000016	0.00000000057	0.0051	0.0000023
Concord NWS via:								
Two High Population Ports	0.000099	0.000039	0.000013	0.000000042	0.000000016	0.0000000057	0.052	0.000022
One High and One Intermediate Population Port	0.000069	0.000027	0.0000093	0.000000029	0.000000011	0.0000000036	0.036	0.000015
One High and One Low Population Port	0.000060	0.000024	0.0000081	0.000000025	0.0000000099	0.0000000034	0.032	0.000013
Two Intermediate Population Ports	0.000038	0.000015	0.0000051	0.000000017	0.0000000064	0.0000000016	0.020	0.0000087
One Intermediate and One Low Population Port	0.000029	0.000011	0.0000039	0.000000013	0.0000000049	0.0000000014	0.016	0.0000067

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
Two Low Population Ports	0.000021	0.0000079	0.0000027	0.0000000090	0.0000000034	0.0000000012	0.011	0.0000047
Direct	0.000017	0.0000065	0.0000022	0.0000000071	0.0000000028	0.00000000096	0.0088	0.0000038

These risk estimates provide an estimate of the range of the port accident risks that would result from the basic implementation of Management Alternative 1 via the use of a wide range of ports. The ports of Elizabeth, Philadelphia, and Long Beach were included in the analysis as ports of entry even though they did not survive the port screening criteria. However, because of the high populations around these ports, their use provides an estimate of the highest risks associated with the shipment of foreign research reactor spent nuclear fuel into the United States. These risks can be contrasted with the risks associated with the shipment of the foreign research reactor spent nuclear fuel through MOTSU, which has an extremely low population around the port.

The port accident risks associated with the entire program range from a high of 0.070 person-rem and 0.000029 LCF, which assumes that all shipments would be made through two high population intermediate ports into Elizabeth, to a low of 0.0007 person-rem and 0.00000032 LCF, which assumes that the shipments are made directly into MOTSU. In the worst case analyzed the mean risks associated with port accidents results in an approximately one-in-a-thousand chance of a single LCF. The highest risks associated with a port that did meet the port selection criteria (assuming no restrictions on the selection of intermediate ports) is 0.000022 LCF. If, in addition, all intermediate port calls are restricted to port cities of similar size to those that meet the selection criteria, the highest calculated risk is reduced to 0.000009 LCF, approximately a one-in-a-hundred thousand chance of a single LCF.

D.5.6 Port Accident Impacts for Implementation Alternatives

Two implementation alternatives to Management Alternative 1 were identified that could impact the results of the port accident risk analysis that was developed for the basic implementation case. They are: 1a, Accepting Fuel from Developing Countries Only, and 2a, Accepting Fuel for Only Five Years. Developing countries are countries other than high income economies. Both of the implementation alternatives change the number of transportation casks containing foreign research reactor spent nuclear fuel that would be shipped to the United States.

The difference in the number of shipments does not affect the per-transit probability of an accident. The conditional probabilities of a severity category 4, 5, or 6 accident also do not change. On a per-shipment basis, the probability an accident of each of these severity categories is identical to the estimates used in the analysis of the basic implementation.

The consequences associated with each of the three accident severity categories also do not change just due to the change in the number of shipments. Since neither the probability nor the consequences of the accidents change, the per-shipment risks are identical to those of the basic implementation.

These alternatives are discussed in the following paragraphs.

Acceptance of Foreign Research Reactor Spent Nuclear Fuel from Developing Countries Only: Developing countries are defined as countries other than high-income economies. Under this alternative 168 transportation casks of foreign research reactor spent nuclear fuel would be shipped to the United States (see Appendix C.4.2 for details). All of these shipments would be shipped by ocean vessel and, therefore, would enter the United States through ports.

In addition to a reduced number of shipments associated with this alternative, the mix of fuel types changes. In the basic implementation of Management Alternative 1, most of the foreign research reactor spent nuclear fuel shipments would be BR-2 type fuel. Only about 20 percent of the shipments would be of the TRIGA fuel type. From the information provided in Appendix B, most of the shipments from countries other than high-income economies would be TRIGA fuel. Of the 168 shipments under this implementation alternative, 109 are TRIGA shipments. The remaining 59 shipments are BR-2 fuel shipments.

The risks of the basic implementation of Management Alternative 1, provided in Table D-46, have been recalculated to incorporate the change in the number and makeup of the shipments associated with this implementation alternative. These results are presented in Table D-47. The highest calculated port accident risks are associated with the shipment of all of the foreign research reactor spent nuclear fuel through the port of Elizabeth via two high population intermediate ports. The port accident risks for this implementation alternative for this route are 0.0098 person-rem and 0.000004 LCF. The lowest calculated impacts are for the shipment of all of the material directly into MOTSU (no intermediate port calls) which results in port accident risks of 0.000095 person-rem and 0.000000045 LCF.

Table D-47 Summary of Risk and Population Exposure—For the Implementation Alternative of Acceptance of Foreign Research Reactor Spent Nuclear Fuel Only From Countries Other than High-Income Economies

Port	*Exposure (person-rem)*	*Risk (LCF)*
Elizabeth via:		
Two High Population Ports	0.0098	0.0000041
One High and One Intermediate Population Port	0.0084	0.0000035
One High and One Low Population Port	0.0080	0.0000034
Two Intermediate Population Ports	0.0041	0.0000018
One Intermediate and One Low Population Port	0.0038	0.0000016
Two Low Population Ports	0.0034	0.0000014
Direct	0.0031	0.0000013
Long Beach via:		
Two High Population Ports	0.0081	0.0000034
One High and One Intermediate Population Port	0.0059	0.0000025
One High and One Low Population Port	0.0052	0.0000022
Two Intermediate Population Ports	0.0037	0.0000015
One Intermediate and One Low Population Port	0.0030	0.0000013
Two Low Population Ports	0.0023	0.0000010
Direct	0.0021	0.00000087
Philadelphia via:		
Two High Population Ports	0.0079	0.0000033
One High and One Intermediate Population Port	0.0065	0.0000028
One High and One Low Population Port	0.0062	0.0000026
Two Intermediate Population Ports	0.0023	0.00000010
One Intermediate and One Low Population Port	0.0019	0.00000084

Port	Exposure (person-rem)	Risk (LCF)
Two Low Population Ports	0.0016	0.00000068
Direct	0.0013	0.00000055
Portland via:		
Two High Population Ports	0.0066	0.0000028
One High and One Intermediate Population Port	0.0044	0.0000018
One High and One Low Population Port	0.0037	0.0000016
Two Intermediate Population Ports	0.0021	0.00000085
One Intermediate and One Low Population Port	0.0015	0.00000060
Two Low Population Ports	0.00082	0.00000035
Direct	0.00054	0.00000022
Norfolk via:		
Two High Population Ports	0.0070	0.0000030
One High and One Intermediate Population Port	0.0056	0.0000024
One High and One Low Population Port	0.0052	0.0000022
Two Intermediate Population Ports	0.0014	0.00000061
One Intermediate and One Low Population Port	0.0010	0.00000045
Two Low Population Ports	0.00064	0.00000029
Direct	0.00035	0.00000016
Charleston (Wando Terminal) via:		
Two High Population Ports	0.0069	0.0000029
One High and One Intermediate Population Port	0.0054	0.0000023
One High and One Low Population Port	0.0051	0.0000021
Two Intermediate Population Ports	0.0012	0.00000054
One Intermediate and One Low Population Port	0.00084	0.00000038
Two Low Population Ports	0.00048	0.00000022
Direct	0.00020	0.000000089
Charleston NWS via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0054	0.0000023
One High and One Low Population Port	0.0051	0.0000021
Two Intermediate Population Ports	0.0012	0.00000054
One Intermediate and One Low Population Port	0.00084	0.00000038
Two Low Population Ports	0.00048	0.00000022
Direct	0.00020	0.000000089
MOTSU via:		
Two High Population Ports	0.0067	0.0000028
One High and One Intermediate Population Port	0.0053	0.0000022
One High and One Low Population Port	0.0050	0.0000021
Two Intermediate Population Ports	0.0011	0.00000049
One Intermediate and One Low Population Port	0.00074	0.00000034
Two Low Population Ports	0.00038	0.00000018
Direct	0.000095	0.000000045
Galveston via:		
Two High Population Ports	0.0073	0.0000031
One High and One Intermediate Population Port	0.0059	0.0000025
One High and One Low Population Port	0.0055	0.0000023
Two Intermediate Population Ports	0.0017	0.00000074
One Intermediate and One Low Population Port	0.0013	0.00000058
Two Low Population Ports	0.00094	0.00000043
Direct	0.00066	0.00000029
Jacksonville via:		
Two High Population Ports	0.0069	0.0000029

Port	Exposure (person-rem)	Risk (LCF)
One High and One Intermediate Population Port	0.0055	0.0000023
One High and One Low Population Port	0.0052	0.00000022
Two Intermediate Population Ports	0.0013	0.00000057
One Intermediate and One Low Population Port	0.00093	0.00000042
Two Low Population Ports	0.00056	0.00000026
Direct	0.00028	0.00000013
Savannah via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0055	0.0000023
One High and One Low Population Port	0.0051	0.0000021
Two Intermediate Population Ports	0.0012	0.00000054
One Intermediate and One Low Population Port	0.00085	0.00000039
Two Low Population Ports	0.00049	0.00000023
Direct	0.00021	0.000000095
Wilmington via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0054	0.0000023
One High and One Low Population Port	0.0050	0.0000021
Two Intermediate Population Ports	0.0012	0.00000052
One Intermediate and One Low Population Port	0.00081	0.00000037
Two Low Population Ports	0.00045	0.00000021
Direct	0.00016	0.000000074
Tacoma via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0045	0.0000019
One High and One Low Population Port	0.0039	0.0000017
Two Intermediate Population Ports	0.0023	0.00000095
One Intermediate and One Low Population Port	0.0017	0.00000070
Two Low Population Ports	0.00010	0.00000045
Direct	0.00072	0.00000032
Concord NWS via:		
Two High Population Ports	0.0073	0.0000031
One High and One Intermediate Population Port	0.0051	0.0000021
One High and One Low Population Port	0.0044	0.0000019
Two Intermediate Population Ports	0.0028	0.0000012
One Intermediate and One Low Population Port	0.0022	0.00000091
Two Low Population Ports	0.0015	0.00000066
Direct	0.0012	0.00000053

Acceptance of Foreign Research Reactor Spent Nuclear Fuel for 5 Years Only: Under this implementation alternative, 586 transportation casks of foreign research reactor spent nuclear fuel would be shipped to the United States. All of these shipments would be shipped by ocean vessel and would enter the United States through ports.

In addition to a reduced number of shipments associated with this implementation alternative, the mix of fuel types changes slightly. From the information provided in Appendix B, 376 of the 586 shipments in this alternative are BR-2 spent fuel shipments, 56 are RHF, and 154 are TRIGA.

The risks of the basic implementation of Management Alternative 1, provided in Table D-46, have been recalculated to incorporate the change in the number and makeup of the shipments associated with this implementation alternative. These results are presented in Table D-48. The highest calculated port accident risks are associated with the shipment of all of the foreign research reactor spent nuclear fuel through the port of Elizabeth via two high population intermediate ports. The port accident risks for the implementation alternative for this route are 0.055 person-rem and 0.000023 LCF. The lowest calculated impacts are for the shipment of all of the material directly into MOTSU (no intermediate port calls) which results in port accident risks of 0.00055 person-rem and 0.00000026 LCF.

Table D-48 Summary of Risk and Population Exposure—For the Implementation Alternative of a 5-Year Acceptance Duration

Port	*Exposure (person-rem)*	*Risk (LCF)*
Elizabeth via:		
Two High Population Ports	0.055	0.000023
One High and One Intermediate Population Port	0.047	0.000020
One High and One Low Population Port	0.045	0.000019
Two Intermediate Population Ports	0.023	0.000010
One Intermediate and One Low Population Port	0.021	0.0000091
Two Low Population Ports	0.019	0.0000082
Direct	0.018	0.0000074
Long Beach via:		
Two High Population Ports	0.046	0.000019
One High and One Intermediate Population Port	0.033	0.000014
One High and One Low Population Port	0.030	0.000013
Two Intermediate Population Ports	0.021	0.0000089
One Intermediate and One Low Population Port	0.017	0.0000073
Two Low Population Ports	0.013	0.0000057
Direct	0.012	0.0000049
Philadelphia via:		
Two High Population Ports	0.045	0.000019
One High and One Intermediate Population Port	0.037	0.000016
One High and One Low Population Port	0.035	0.000015
Two Intermediate Population Ports	0.013	0.0000057
One Intermediate and One Low Population Port	0.011	0.0000048
Two Low Population Ports	0.0089	0.0000039
Direct	0.0073	0.0000031
Portland via:		
Two High Population Ports	0.038	0.000016
One High and One Intermediate Population Port	0.025	0.000011
One High and One Low Population Port	0.021	0.0000090
Two Intermediate Population Ports	0.012	0.0000052
One Intermediate and One Low Population Port	0.0084	0.0000037
Two Low Population Ports	0.0047	0.0000021
Direct	0.0031	0.0000013
Norfolk via:		
Two High Population Ports	0.040	0.000017
One High and One Intermediate Population Port	0.032	0.000013
One High and One Low Population Port	0.030	0.000013
Two Intermediate Population Ports	0.0078	0.0000035
One Intermediate and One Low Population Port	0.0057	0.0000026
Two Low Population Ports	0.0036	0.0000017
Direct	0.0020	0.00000089
Charleston (Wando Terminal) via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0069	0.0000031

Port	Exposure (person-rem)	Risk (LCF)
One Intermediate and One Low Population Port	0.0048	0.0000022
Two Low Population Ports	0.0028	0.0000013
Direct	0.0011	0.00000051
Charleston NWS via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0066	0.0000031
One Intermediate and One Low Population Port	0.0048	0.0000022
Two Low Population Ports	0.0025	0.0000013
Direct	0.00087	0.00000054
MOTSU via:		
Two High Population Ports	0.038	0.000016
One High and One Intermediate Population Port	0.030	0.000013
One High and One Low Population Port	0.028	0.000012
Two Intermediate Population Ports	0.0063	0.0000028
One Intermediate and One Low Population Port	0.0042	0.0000019
Two Low Population Ports	0.0022	0.0000010
Direct	0.00055	0.00000028
Galveston via:		
Two High Population Ports	0.041	0.000018
One High and One Intermediate Population Port	0.033	0.000014
One High and One Low Population Port	0.031	0.000013
Two Intermediate Population Ports	0.0095	0.0000042
One Intermediate and One Low Population Port	0.0074	0.0000033
Two Low Population Ports	0.0054	0.0000024
Direct	0.0037	0.0000017
Jacksonville via:		
Two High Population Ports	0.039	0.000017
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0073	0.0000033
One Intermediate and One Low Population Port	0.0053	0.0000024
Two Low Population Ports	0.0032	0.0000015
Direct	0.0016	0.00000072
Savannah via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0069	0.0000031
One Intermediate and One Low Population Port	0.0049	0.0000022
Two Low Population Ports	0.0028	0.0000013
Direct	0.0012	0.00000055
Wilmington via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0067	0.0000030
One Intermediate and One Low Population Port	0.0046	0.0000021
Two Low Population Ports	0.0026	0.0000012
Direct	0.00093	0.00000042

Port	Exposure (person-rem)	Risk (LCF)
Tacoma via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.026	0.0000011
One High and One Low Population Port	0.022	0.0000094
Two Intermediate Population Ports	0.013	0.0000057
One Intermediate and One Low Population Port	0.0094	0.0000041
Two Low Population Ports	0.0057	0.0000026
Direct	0.0041	0.0000018
Concord NWS via:		
Two High Population Ports	0.041	0.000017
One High and One Intermediate Population Port	0.029	0.000012
One High and One Low Population Port	0.025	0.000011
Two Intermediate Population Ports	0.016	0.0000070
One Intermediate and One Low Population Port	0.012	0.0000054
Two Low Population Ports	0.0086	0.0000037
Direct	0.0070	0.0000030

D.5.7 Port Accident Impacts Associated with Management Alternative 2

Of the two subalternatives under Management Alternative 2, only subalternative 1b requires assessment of the impacts of accidents in port. This subalternative involves overseas reprocessing of foreign research reactor spent nuclear fuel. Under this subalternative, which is explained in detail in Chapter 2, up to eight transportation casks of vitrified high-level waste might pass through U.S. ports on their way to storage sites in the United States. The port accident impacts associated with this subalternative are evaluated below.

Foreign Reprocessing with Shipment of Vitrified Waste to a U.S. Storage Facility: In this subalternative to Management Alternative 2, all of the foreign research reactor spent nuclear fuel (including that generated in Canada) would be sent to either Great Britain or France for reprocessing and part or all of the vitrified high-level waste generated in the process could be shipped to the United States. Based on the reprocessing of approximately 23 metric tons of spent nuclear fuel (all of the fuel considered by the basic implementation of Management Alternative 1), enough vitrified high-level waste would be generated to require the transportation of up to eight transportation casks carrying logs of vitrified high-level waste to the United States.

The consequences of an accident in port involving a cask of vitrified high-level waste could not be derived from the analysis of the port accidents for the foreign research reactor spent nuclear fuel. Two significant differences in the contents of the cask carrying vitrified high-level waste and the casks carrying foreign research reactor spent nuclear fuel dictate that revised source terms be calculated for the vitrified high-level waste case. The release fractions associated with the accident severity categories are different for the vitrified high-level waste than they are for the foreign research reactor spent nuclear fuel. Based on previous DOE efforts (DOE, 1994b) the release fractions for vitrified high-level waste are the same for all three release categories (categories 4, 5, and 6). Vitrified waste release fractions are relatively insensitive to the affects of the fires that differentiate the category 5 and 6 accidents from the category 4 accidents. The release fractions used in this analysis are a factor of 0.05 higher than those used in the referenced analysis because the use of the MACCS code eliminates the need to describe a respirable fraction of the release. In the referenced analysis, the release fraction was determined and then modified by the respirable fraction (0.05) to use the value of 0.00000005 (5.0E-08) used in that analysis. Without the respirable fraction modification the release fraction is 0.000001 (1.0E-06). This is the release fraction used in the analysis of the vitrified high-level waste shipment port accident analysis.

These release fractions apply to all material in the vitrified high-level waste. Each isotope contained in the glassified waste has been assigned the same release fraction.

All of the wastes generated in reprocessing the foreign research reactor spent nuclear fuel would be transported in no more than eight casks, compared to the 837 marine and overland shipments of spent nuclear fuel required under the basic implementation of Management Alternative 1. This means that the curie content of the vitrified high-level waste could be approximately 100 times the content of a single transportation cask of foreign research reactor spent nuclear fuel.

In this analysis no credit has been taken for the reduction in the curie content of the vitrified high-level waste due to the natural decay that would result during the temporary storage of the vitrified high-level waste at the reprocessing facility. One of the options considered for this subalternative includes the storage of this material at the reprocessing facility until a permanent U.S. facility is ready to receive it for storage. Even if the material is not held until a permanent facility is available, some temporary storage at the reprocessing facility would probably be necessary. In either case, the reduction in the curie content of the waste logs has conservatively not been incorporated into this analysis. The risks associated with the shipment of aged vitrified high-level waste would be less, proportional to the reduction in the curie content, than the risks associated with the shipment of recently reprocessed material of the same volume. Therefore, while the risks calculated in this analysis are more appropriate for the shipment of recently reprocessed waste, the analysis bounds the risks associated with both options.

The isotopic content of the material shipped in one transportation cask of vitrified high-level waste is presented in Table D-49. This estimate was developed by combining the isotopic inventory of every assembly being shipped in the basic implementation of Management Alternative 1 and equally dividing these inventories into eight shipments. This inventory of material was developed from an earlier estimate of the number of foreign research reactor spent nuclear fuel shipments than that analyzed as the basic implementation of Management Alternative 1. The isotopic content of the earlier estimate of the number of shipments is slightly higher than results from the shipments in the basic implementation of Management Alternative 1, for every isotope found in the vitrified high-level waste. Therefore, the estimate used to generate the data in Table D-49 is slightly conservative.

The consequence analysis was performed using the MACCS code utilizing the inventory and release fraction data presented above. Since it is anticipated that the vitrified high-level waste would be stored, temporarily, at the Savannah River Site and the shipments are originating in Europe, only selected East Coast sites were analyzed. Port accident risks were analyzed for the ports of Philadelphia, Charleston, and MOTSU. Also, it has been assumed that the vitrified high-level waste shipments would be made on vessels that would not make intermediate port calls, i.e., on a chartered vessel. The results of these consequences analyses are presented in Table D-50. The highest mean value for an exposure to the MEI is 740 mrem for a 50-year dose to that individual. This corresponds to a LCF consequence of 0.00035.

The probability of an accident in port has been modeled using the data generated for the analysis of the basic implementation of Management Alternative 1. Although the use of a chartered (especially a purpose-built) ship could result in somewhat lower accident frequencies for each of the severity categories, these differences were judged to be minor and were not incorporated into the analysis. The port accident risks associated with the shipment of a single cask and of all eight casks containing the entire inventory of vitrified high-level waste generated in the reprocessing of all of the foreign research reactor spent nuclear fuel considered in the basic implementation of Management Alternative 1 are presented in Table D-51.

Table D-49 Radionuclide Inventory for Each of Eight Vitrified High-Level Waste Shipments

Radionuclide	*Vitrified High-Level Waste Inventory (Ci)*	*Radionuclide*	*Vitrified High-Level Waste Inventory (Ci)*
Hydrogen-3	7,302	Cerium-141	559,300
Krypton-85	207,000	Cerium-144 Promethium-144	24,890,000
Strontium-89	3,072,000	Promethium-147	3,703,000
Strontium-90 Yttrium-90	1,743,000	Promethium-148m	7,133
Yttrium-91	5,477,000	Europium-154	62,390
Zirconium-95	8,079,000	Europium-155	12,900
Niobium-95	16,540,000	Plutonium-238	8,484
Ruthenium-103 Rh-103m	716,000	Plutonium-239	405
Ruthenium-106 Rh-106m	1,882,000	Plutonium-240	326
Tin-123	33,340	Plutonium-241	78,440
Antimony-125	75,700	Americium-241	98
Tellurium-125m	18,060	Americium-242m	0.67
Tellurium-127M	69,720	Americium-243	1.4
Tellurium-129M	15,870	Curium-244	122
Cesium-134	1,413,000	Curium-242	990
Cesium-137	1,743,000		

Table D-50 Port Accident Consequences for Vitrified High-Level Waste

Location	*Mean Accident Consequences*		*99th Percentile Consequences*	
	Population Exposure (person-rem)	*LCF*	*Population Exposure (person-rem)*	*LCF*
MOTSU at the Dock	93.1	0.04	572	0.25
MOTSU in the Channel	66.1	0.029	332	0.13
Charleston at the Dock	202	0.088	747	0.32
Charleston in the Channel	293	0.13	2450	1.02
Philadelphia at the Dock	1250	0.54	5110	2.12
Philadelphia in the Channel	733	0.32	2990	1.21

The port accident risks associated with the implementation of this subalternative to Management Alternative 2 results in a negligible risk to the public. The highest mean port accident risk results in a less than one-in-ten thousand chance of a single LCF.

D.5.8 Port Accident Impacts Associated with a Combination of Returning Foreign Research Reactor Spent Nuclear Fuel and Overseas Management

In addition to evaluating the port accident impacts for the various alternatives associated with bringing all of the foreign research reactor spent nuclear fuel to the United States (Management Alternative 1) and managing all of the spent nuclear fuel overseas (Management Alternative 2), a hybrid scenario was analyzed. In this scenario, those countries that have the capability to store high-level waste would be encouraged to process aluminum-based foreign research reactor spent nuclear fuel and to accept the resulting high-level waste. For this scenario, those countries are assumed to be Belgium, France, Germany, Italy, Spain, Switzerland, and the United Kingdom. The United States would accept the foreign

Table D-51 Port Accident Risks for the Acceptance of Vitrified High-Level Waste

Port	Risk per Shipment of One Cask of Waste		Risk of the Entire Waste Acceptance Option	
	Population Dose (person-rem)	LCF	Population Dose (person-rem)	LCF
Philadelphia	0.006	0.000003	0.05	0.00002
Charleston	0.001	0.0000007	0.01	0.000005
MOTSU	0.0005	0.0000002	0.004	0.000002

research reactor spent nuclear fuel from those countries deemed not to have the high-level waste storage capability. In this option, this includes all of the countries identified in Table C-1, except for those listed above. Under the hybrid scenario, 452 shipments of spent nuclear fuel are assumed to be sent to the United States through U.S. ports, excluding shipments of Canadian origin, which are assumed to be transported overland. Of these, 290 are of the BR-2 fuel type and 162 are of the TRIGA type.

In analyzing the exposure and risk associated with this scenario, much of the information that was developed for Management Alternative 1 can be used. Both the per-transit probability of an accident and the conditional probabilities of severity category 4, 5, and 6 accidents are valid for this hybrid scenario. The consequences associated with each of the three accident severity categories also do not change, because the only thing that is changing is the number of shipments. Since neither the probability nor the consequences of the accidents change, the per-shipment risks are identical to those of the basic implementation of Management Alternative 1.

The risks associated with the basic implementation of Management Alternative 1 (Table D-46) have been recalculated to incorporate the change in the number and makeup of the shipments associated with the hybrid scenario. These results are presented in Table D-52. The highest calculated port accident risks are associated with the shipment of all of the foreign research reactor spent nuclear fuel through the port of Elizabeth via two high population intermediate ports. The port accident risks for the Management Alternative for this route are 0.041 person-rem and 0.000017 LCF. The lowest calculated impacts are for the shipment of all the material directly into MOTSU (no intermediate port calls), which results in port accident risk of 0.0004 person-rem and 1.9×10^{-7} LCF.

Table D-52 Summary of Risk and Population Exposure—For the Hybrid Scenario

Port	Exposure (person-rem)	Risk (LCF)
Elizabeth via:		
Two High Population Ports	0.041	1.7×10^{-5}
One High and One Intermediate Population Port	0.035	1.5×10^{-5}
One High and One Low Population Port	0.034	1.4×10^{-5}
Two Intermediate Population Ports	0.017	7.5×10^{-6}
One Intermediate and One Low Population Port	0.016	6.8×10^{-6}
Two Low Population Ports	0.014	6.1×10^{-6}
Direct	0.013	5.5×10^{-6}
Long Beach via:		
Two High Population Ports	0.034	1.5×10^{-5}
One High and One Intermediate Population Port	0.025	1.1×10^{-5}
One High and One Low Population Port	0.022	9.4 x 10-6
Two Intermediate Population Ports	0.015	6.6 x 10-6
One Intermediate and One Low Population Port	0.013	5.4 x 10-6
Two Low Population Ports	0.0099	4.3×10^{-6}
Direct	0.0087	3.7×10^{-6}
Philadelphia via:		
Two High Population Ports	0.033	1.4×10^{-5}

Port	Exposure (person-rem)	Risk (LCF)
Two High Population Ports	0.033	1.4×10^{-5}
One High and One Intermediate Population Port	0.028	1.2×10^{-5}
One High and One Low Population Port	0.026	1.1×10^{-5}
Two Intermediate Population Ports	0.0097	4.2×10^{-6}
One Intermediate and One Low Population Port	0.0082	3.6×10^{-6}
Two Low Population Ports	0.0066	2.9×10^{-6}
Direct	0.0054	2.3×10^{-6}
Portland via:		
Two High Population Ports	0.028	1.2×10^{-5}
One High and One Intermediate Population Port	0.018	7.8×10^{-6}
One High and One Low Population Port	0.016	6.7×10^{-6}
Two Intermediate Population Ports	0.0090	3.9×10^{-6}
One Intermediate and One Low Population Port	0.0063	2.7×10^{-6}
Two Low Population Ports	0.0035	1.6×10^{-6}
Direct	0.0023	9.8×10^{-7}
Norfolk via:		
Two High Population Ports	0.030	1.2×10^{-5}
One High and One Intermediate Population Port	0.024	1.0×10^{-5}
One High and One Low Population Port	0.022	9.3×10^{-6}
Two Intermediate Population Ports	0.0058	2.6×10^{-6}
One Intermediate and One Low Population Port	0.0043	1.9×10^{-6}
Two Low Population Ports	0.0027	1.2×10^{-6}
Direct	0.0015	6.7×10^{-7}
Charleston (Wando Terminal) via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.7×10^{-6}
One High and One Low Population Port	0.021	9.0×10^{-6}
Two Intermediate Population Ports	0.0051	2.3×10^{-6}
One Intermediate and One Low Population Port	0.0036	1.6×10^{-6}
Two Low Population Ports	0.0021	9.5×10^{-7}
Direct	0.00083	3.8×10^{-7}
Charleston NWS via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.7×10^{-6}
One High and One Low Population Port	0.021	9.1×10^{-6}
Two Intermediate Population Ports	0.0049	2.3×10^{-6}
One Intermediate and One Low Population Port	0.0034	1.6×10^{-6}
Two Low Population Ports	0.0019	9.8×10^{-7}
Direct	0.00041	4.0×10^{-7}
MOTSU via:		
Two High Population Ports	0.028	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.5×10^{-6}
One High and One Low Population Port	0.0021	8.8×10^{-6}
Two Intermediate Population Ports	0.0047	2.1×10^{-6}
One Intermediate and One Low Population Port	0.0032	1.4×10^{-6}
Two Low Population Ports	0.0016	7.6×10^{-7}
Direct	0.00041	1.9×10^{-7}
Galveston via:		
Two High Population Ports	0.031	1.3×10^{-5}
One High and One Intermediate Population Port	0.025	1.1×10^{-5}
One High and One Low Population Port	0.023	9.9×10^{-6}
Two Intermediate Population Ports	0.0071	3.2×10^{-6}

Port	Exposure (person-rem)	Risk (LCF)
One Intermediate and One Low Population Port	0.0056	2.5×10^{-6}
Two Low Population Ports	0.0040	1.8×10^{-6}
Direct	0.0028	1.2×10^{-6}
Jacksonville via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.9×10^{-6}
One High and One Low Population Port	0.022	9.2×10^{-6}
Two Intermediate Population Ports	0.0055	2.4×10^{-6}
One Intermediate and One Low Population Port	0.0039	1.8×10^{-6}
Two Low Population Ports	0.0024	1.1×10^{-6}
Direct	0.0012	5.3×10^{-7}
Savannah via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.7×10^{-6}
One High and One Low Population Port	0.022	9.1×10^{-6}
Two Intermediate Population Ports	0.0052	2.3×10^{-6}
One Intermediate and One Low Population Port	0.0036	1.7×10^{-6}
Two Low Population Ports	0.0021	9.8×10^{-7}
Direct	0.00088	4.1×10^{-7}
Wilmington via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.6×10^{-6}
One High and One Low Population Port	0.021	9.0×10^{-6}
Two Intermediate Population Ports	0.0050	2.2×10^{-6}
One Intermediate and One Low Population Port	0.0035	1.6×10^{-6}
Two Low Population Ports	0.0019	8.9×10^{-7}
Direct	0.00069	3.2×10^{-7}
Tacoma via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.019	8.2×10^{-6}
One High and One Low Population Port	0.016	7.0×10^{-6}
Two Intermediate Population Ports	0.0098	4.2×10^{-6}
One Intermediate and One Low Population Port	0.0070	3.1×10^{-6}
Two Low Population Ports	0.0043	1.9×10^{-6}
Direct	0.0030	1.3×10^{-6}
Concord NWS via:		
Two High Population Ports	0.031	1.3×10^{-5}
One High and One Intermediate Population Port	0.021	9.1×10^{-6}
One High and One Low Population Port	0.019	7.9×10^{-6}
Two Intermediate Population Ports	0.012	5.1×10^{-6}
One Intermediate and One Low Population Port	0.0092	4.0×10^{-6}
Two Low Population Ports	0.0064	2.8×10^{-6}
Direct	0.0052	2.2×10^{-6}

D.5.9 Consequences of Sabotage or Terrorist Attack

This section provides an evaluation of impacts that could potentially result from a malicious act on a shipment of foreign research reactor spent nuclear fuel. In no instance, even in severe cases such as those discussed below, could a nuclear explosion or permanent contamination of the environment leading to condemnation of land occur. Furthermore, DOE considers that, due to the security measures that would be in place for any spent nuclear fuel shipments, such attacks would be unlikely to occur. At a minimum, the extent or effects of any such attacks, would be mitigated by the security measures.

Since it is impossible to determine with certainty the probability of a deliberate act of sabotage or terrorist attack, this section presents an analysis of potential consequences of sabotage or terrorist attack on a spent nuclear fuel shipping cask, and does not attempt to estimate the risk of such an activity. Although judged very unlikely to actually occur, a malicious attack on a foreign research reactor spent nuclear fuel shipping cask has been postulated to occur at a U.S. port or during transportation from the port to the management site, for purposes of illustrating the effects that might result from such an event.

The spectrum of attacks that can be postulated is broad, falling into three categories or scenarios: (1) exploding a bomb near a shipping cask, (2) attacking a cask with a shaped charge, or an armor-piercing weapon (i.e., an anti-tank weapon), and (3) hijacking (stealing) a shipping cask. None of the scenarios considered would lead to a criticality accident.

D.5.9.1 Exploding a Bomb Near a Shipping Cask

This sabotage/terrorist attack scenario assumes that a large bomb, similar to that detonated in Oklahoma City in April of 1995, is detonated in the immediate vicinity of a spent nuclear fuel shipping cask. The primary threats to the cask integrity would arise from: (1) direct blast forces (shock wave) from the bomb, (2) impact forces from fragments (e.g., motor vehicle parts) generated by the bomb, and (3) other dynamic forces such as a roll-over of the cask transport vehicle in response to the blast forces. The casks are rugged structures that would be expected to survive the effects of a nearby bomb explosion with no significant loss of integrity. At worst, the blast might produce a crack in the wall of the cask. In any case, all spent nuclear fuel elements would remain inside the cask. Blast-related damage might, however, reduce the effectiveness of cask shielding and/or cause locally higher dose rates outside the cask (e.g., from damaged shielding areas and radiation streaming through a crack in the cask wall).

Although no mechanism has been postulated that could cause such an event, an analysis of a total loss of cask shielding has been performed for the purposes of demonstrating limiting case effects of an attack on a spent nuclear fuel shipping cask, such as that discussed above. The analysis scenario assumes that the cask was full of a highly irradiated foreign research reactor spent nuclear fuel, and that the spent nuclear fuel elements were spread on the ground producing the highest possible direct dose rate. For the calculation of direct dose, no credit was taken for self-shielding of the spent fuel, and it was assumed that no other obstacle would exist between the spent nuclear fuel and individual members of the public. Since the spent nuclear fuel would be a solid metal structure, this analysis assumes that no spent nuclear fuel damage occurs, therefore, no radioactive materials would be dispersed. The results of this unrealistically conservative analysis are shown in Figure D-60. This figure provides a conservative estimate of the direct dose rate (rem per hour) to an individual member of the public versus distance from a spent nuclear fuel pile consisting of 30 highly irradiated fuel elements. Based on the results of this hypothetical, conservative analysis, an evacuation distance of about 900 meters (3000 ft) would be sufficient to maintain a dose rate of less than 10 mrem per hour, (or 0.01 rem per hour). This is a very conservative evacuation distance, but it would provide a good measure for consideration by an emergency response team. This scenario would result in minimal or no contamination of the area where it occurred and once the spent nuclear fuel was shielded, the evacuation zone would be greatly reduced. Once the spent nuclear fuel was removed from the site, the area would be decontaminated, if necessary, before it returned to normal.

D.5.9.2 Attacking a Cask with a Shaped Charge or Armor-Piercing Weapon

If a cask were attacked by an armor-piercing weapon or a shaped charge, the cask would be penetrated and spent nuclear fuel elements inside the cask could be damaged. An analysis of a hypothetical attack on a spent nuclear fuel shipping cask using a shaped charge was performed using the MACCS code. The

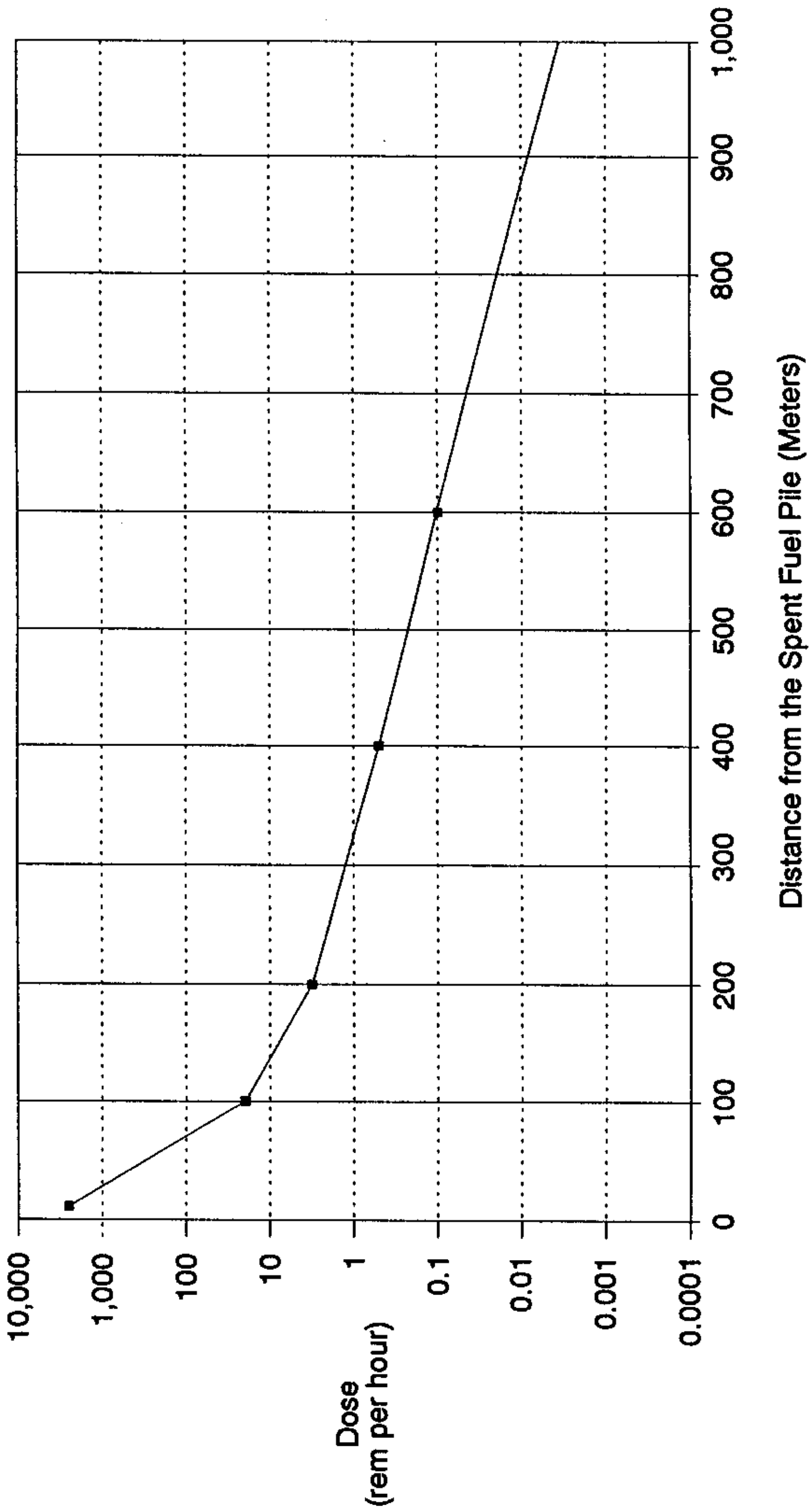

Figure D-60 Direct Dose vs Distance to an Individual Member of the Public

accident was assumed to occur on a city street in a highly populated area near the harbor where the spent nuclear fuel cask was transferred to a truck after trans oceanic shipment from overseas. The analysis assumed that the cask contained the highest radionuclide inventory, and the blast released all of the noble gases and one percent of the bulk of the spent nuclear fuel as airborne aerosols. The one percent of bulk spent nuclear fuel release assumption was based on measurements of aerosols released during tests where spent nuclear fuel was explosively disrupted. These tests yielded spent nuclear fuel release mass fractions that ranged from 0.05 to 2.5 percent (Sanders, et al., 1992). The blast energy would be quickly dissipated and the released fission products and gases and aerosols were assumed to be relatively cool; thus no plume rise was assumed to occur. These assumptions are very conservative and the results provide an enveloping estimate of consequences on the environmental and health effects. The MACCS calculations estimated a population dose of 208,000 person-rem with no acute fatalities or short-term adverse health effects among the exposed population. The MACCS results estimated that 91 latent cancer fatalities could occur among the 16 million persons living within 80 kilometers (50 miles) of the attack. The average individual lifetime radiation dose among the one to two million people who would be exposed is estimated to be about 200 mrem. This is less than one percent of a person's lifetime natural background radiation dose. This evaluation did not consider any evacuation and/or sheltering activities after the attack. MACCS also estimated a contamination distance of about 1 kilometer (0.6 miles) down wind from the attack. This distance, though conservative, could be used by an emergency response team for evacuation purposes. Of course, any actual evacuation distance would be determined on a case-by-case basis, if such an event were ever to occur. Mitigation activities in the aftermath of such an explosion, as required by law (EPA), would reduce the size of the contaminated area drastically and the area could become rehabitable in a short period of time. It is important to bear in mind that the explosion itself would be likely to produce fatalities, injuries and property damage that far exceed that caused by any release of radioactive material from the spent nuclear fuel.

In a terrorist attack using an anti-tank weapon, any cask damage and resulting consequences would be less severe than the accidents analyzed elsewhere in the EIS. This is because (1) there would be no explosive material inside the cask so the cask would not explode. Therefore, no additional radioactivity, other than that released directly by the projectile, would be forced out of the cask, and (2) there would be no fire to disperse the radioactivity that would be released when the cask was breached. At worst, the consequences of a terrorist attack on a spent nuclear fuel shipping cask with an anti-tank weapon would be similar to that analyzed above for a hypothetical terrorist attack on a cask with a high explosive shaped charge.

D.5.9.3 Hijacking a Shipping Cask

The discret theft of a spent nuclear fuel transportation cask is considered to be very unlikely, due to security measures that would be in place during transportation activities, especially the guarding of the cask, and communication and tracking systems (see Section 2.8 and Appendix H). In addition, the large size and weight of these casks (20 to 30 metric tons) and the inherent radioactivity of the spent nuclear fuel (which could kill a person upon contact) would deter most would-be hijackers. In the event of a hijack attempt, required communications systems would ensure timely notification of authorities who would mobilize response forces. The installed tracking system would allow the location of the cask to be determined in real time, thereby aiding timely interception of hijackers by response forces.

No release of radioactive material or increase in radiation level would be expected during a hijack scenario unless the hijacker could blow up the cask using explosive material (e.g., a shaped charge), or open the cask. In case of a cask explosion using a shaped charge, the consequences would be the same as, or smaller than (depending on the location of the accident), the case described in Section D.5.9.2. If the cask were opened (a lengthy process requiring special tooling), shielding would be decreased and the radiation level in the immediate vicinity of the cask would increase. The cask opening could only be accomplished at great personal risk to hijackers due to large (possibly immediately lethal) radiation exposures that they would receive while handling the unshielded fuel elements.

Should such an attempt be made, the hijackers would not be able to alter the fuel configuration inside the cask to make it critical. Criticality analyses that have been performed in support of the cask certification process consider various fuel and moderation configurations. These analyses are performed to ensure that none of potential configurations that could occur during loading and transport of the cask would lead to a criticality condition. Changing moderating material to achieve criticality, would require special materials that are not readily available (safeguard materials). Based on the time available to the hijackers, and tooling and materials that are needed, DOE considers that the potential for achieving criticality in a hijacked spent nuclear fuel cask is beyond credibility. If the hijackers were to dump the unshielded spent nuclear fuel, the resulting consequences to the public from the bare spent nuclear fuel radiation exposure would be less severe than those already analyzed for other hypothetical scenarios in this appendix.

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